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by

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Lieutenant Commander, United States Navy

Submitted in partial fulfillment of
the requirements for the degree of

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ABSTRACT

A theoretical method of predicting the performance of subsonic, axial flow, multistage turbines is presented together with the digital computor program for computing all the dimensionless performance parameters required to completely define turbine performance. A small two stage turbine, for use in space vehicles, was used to demonstrate the application of the method. A complete set of performance maps were drawn and analyzed. The dimensionless performance parameters for any given flow condition could be obtained from the maps.

The computor program proved to be extremely flexible and useful. The effect of blade row redesign could be easily determined. Comparison of the extremely limited amount of open cycle test data with program results showed that the method would provide a design engineer the means of predicting the performance of a given turbine design. The accuracy of such a prediction was shown to depend greatly upon the estimation of rotor tip clearances and the measurement of flow areas corresponding to the clearance. The computor program provides a means for trial and error determination of the rotor tip clearances when operating at high temperatures if accurate test data is available.

Although the computor program was written in Fortran language for the Control Data Corporation 1604 Computor at the U.S. Naval Postgraduate School, it should be compatible with most computor installations through out the country.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SYMBOLS AND UNITS

SYMBOL	DEFINITION	UNITS
A	Gas flow area measured normal to flow direction	sq. in.
A_e	Minimum blade passage gas flow area	sq. in.
a	Blade opening or distance between blades at the minimum cross section	in.
C_L	Lift coefficient based upon vector mean velocity	
C_o	Theoretical velocity for isentropic expansion from stagnation pressure at entrance to static pressure at discharge	ft/sec
C_p	Specific heat at constant pressure	Btu/lb ^oR
C_{D_k}	Coefficient of drag on blades created by tip clearance pressure losses	
C_{Ds}	Coefficient of drag on blades created by secondary flow pressure losses	
c	Blade chord	in.
D	Diameter	in.
g_c	Gravitational constant	32.174 ft/sec^2
H	Total absolute enthalpy	Btu/lb
H_R	Total relative enthalpy	Btu/lb
H***	Shape parameter; Energy thickness	
ΔH	Total enthalpy drop	Btu/lb
h	Static enthalpy	Btu/lb
h	Blade height	in.
I.D.	Inside diameter of turbine annulus	in.
i	Incidence angle of flow onto a blade row, given by the difference between gas flow angle relative to blade inlet and blade inlet angle	
i_s	Stalling incidence	
J	Conversion factor	778 ft-lb/Btu

k	Radial rotor tip clearance	in.
N	Rotational speed	rpm
n	Polytropic exponent	
O.D.	Outside diameter of turbine annulus	in.
P	Total pressure	psia.
ΔP	Total pressure drop	psia.
p	Static pressure	psia.
q	Free stream dynamic pressure	lb/ft^2
R	Gas constant	ft lb/lb ^oR
S	Entropy	Btu/lb ^oR
s	Blade spacing	in.
T	Gas total temperature	^oR
T_R	Equivalent total temperature at rotor inlet	^oR
T_S	Equivalent total temperature at stator inlet	^oR
ΔT	Gas total temperature drop	^oR
ΔT_{is}	Isentropic gas total temperature drop	^oR
t	Maximum blade thickness	in.
t_e	Trailing edge thickness	in.
U	Perpherial speed at mean diameter	ft/sec
V	Absolute velocity	ft/sec
V_m	Axial component of absolute velocity	ft/sec
V_u	Tangential component of absolute velocity	ft/sec
W	Relative velocity	ft/sec
W_u	Tangential component of relative velocity	ft/sec
$\dot{w}$	Gas mass flow rate	lb/sec

α	Stator gas flow angles	Degrees
α^*	Stator blade angles	Degrees
β	Rotor gas flow angles	Degrees
β^*	Rotor blade angles	Degrees
γ	Ratio of specific heats	
Δ	Small finite interval	
δ^*	Shape parameter; Displacement thickness	
ζ_e	Expansion loss coefficient	
ζ_k	Rotor tip clearance loss coefficient	
ζ_p	Profile loss coefficient	
ζ_s	Secondary loss coefficient	
ζ_t	Total loss coefficient	
ζ_{te}	Trailing edge loss coefficient	
η	Efficiency	
ν	Flow area reduction factor	
λ	Power coefficient; also a factor defining secondary losses	
ρ	Gas density	slugs/ft^3
Φ	Flow function	
ω	Angular velocity	rad./sec

SUBSCRIPTS

cr	Critical
D	Diffusor
e	exit section
eq.	equivalent
m	mean or meridianal
N	Nozzle

o	Total
R	Rotor
S	Stator
T	Turbine
t	Total
t_e	Trailing edge
u	Tangential
w	Work
0--4	Turbine stations

SUPERSCRIPTS

*	Indicates actual blade angles vice flow angles

Note. See Appendix III for Fortran names and their meaning.

A METHOD OF PREDICTING THE PERFORMANCE OF AXIAL FLOW TURBINES USING A DIGITAL COMPUTOR TO DEVELOP PERFORMANCE MAPS

INTRODUCTION

Turbines for driving auxiliary equipment on rocket and space vehicles have become on of the most exacting pieces of turbomachinery in use today. The premium placed on space and weight in these vehicles requires that the size of a turbine be small, yet it is necessary to extract the maximum work for a given input. This means that the turbine must be designed to have high specific work output and efficiency. The effect of size on the efficiency of turbines has not been fully determined, however small turbines require that clearances be small, flow areas exact, leakage losses low, and deflections of the flow in the rotor blade less than 105°, Ref. 1. Regardless of size, calculation of the performance of a turbine must be made using approximate methods.

Although an exact analysis of viscous, compressible flow through an axial turbomachine can never be made, the demand upon the design engineer for an accurate estimation of the performance of a given design has become greater. The greatest difficulty in making an accurate prediction is contending with the large number of variables that play a role in the overall performance of a turbine stage. Since most engineering firms have access to electronic digital computors, a method of analyis involving their use was suggested.

Manual calculation of the efficiency and work output of a multistage turbine for one set of operating conditions is tedious and time consuming. For a two stage turbine, approximately six man-hours of work are required to obtain one constant speed characteristic point as defined by the flow rate, overall pressure ratio, efficiency, and power coefficient. Many combinations of the input parameters are necessary in order to make an accurate estimation of overall turbine performance. In order to provide a quick and accurate method of evaluating the performance of subsonic, axial flow, single or multistage turbines, equations were developed and programed for computor solution so that performance maps could be drawn.

Under the assumption that a multistage axial flow turbine design presented for evaluation would give the blade shapes, flow angles, diameters, clearances, spacing, and all other pertinent data, the computor program developed will allow an accurate evaluation of the performance to be made. The program has been restricted to subsonic flow conditions. No extension of this program can be made to include turbines operating in the supersonic range since a complicated iteration process would be necessary in order to determine the pressure ratio across each blade row. To preserve flow continuity, the deflection of the outflow from a blade row would also have to be considered, Ref. 2.

II. Method in General

A. Simplifying Assumptions

Once a turbine design has been formulated, any estimation of the performance must be made using three dimensional flow conditions as a basis, since three dimensional effects are so important. Due to the complexity of such flows certain assumptions have been made for simplification.

The flow has been assumed to be adiabatic, steady, turbulent, and axial at entry to the nozzle blade row of the first stage. Frictional forces have been ignored in the region between the blade rows, since velocity gradients in that region are much smaller than those found in the boundary layers along the surfaces. The flow between the blade rows has been considered to be axisymmetric and steady, depending solely upon the conditions imposed by the blade rows ahead of a given region. Interference effects between the rows of blades have been ignored. At the mean radius the flow was considered axisymmetric, having axial and tangential velocity components. Since the annulus radial height is usually small compared with the mean radius, the changes of the flow in radial direction have been ignored and the mass flow rate was determined for the conditions at the mean radius.

An assumption was made that the gas outflow angle from a blade row is independent of incidence and Mach number. While this assumption is not precisely true, no appreciable error will be incurred over the efficient operating range of a subsonic turbine, Ref. 1.

Of course the evaluation of the performance of any turbomachine, no matter what method is employed or how many place accuracy a computor can achieve, depends primarily upon the accuracy of the estimation of the losses. These losses are imposed by the frictional forces in the boundary layers along the blade surfaces, by mixing, and by clearance effects. The major simplification of considering the flow path through each stage at one diameter only requires the further assumption that in any one cross-sectional plane of the flow between adjacent blade rows the total pressure, total temperature, and axial velocity are the same at all points. Such an assumption, though widely divorced from fact, may yield correct overall characteristics of a stage if the loss coefficients used are equal to the momentum mean values over the entire cross-sectional plane.

Since the accuracy of the performance calculations rests mainly upon the loss coefficients, it is imparitive that they be as accurate as possible. American and British design methods and cascade test data were researched in order to determine a basis for loss determination. American methods of determining blade row losses are based mainly upon theoretical considerations. A British method of predicting the loss coefficients, Ref. 3, based upon test data derived from overall tests on a variety of turbine stages having blading approximately midway between impulse and reaction types was chosen. The experimental data from which the loss coefficients were obtained had been deduced from tests made at Reynolds numbers in the range of 1×10^5 to 3×10^5, therefore the method could only be used for turbines operating in that range. The test data apply mainly to blades having a conventional profile shape. Most blade shapes in current use in gas turbines fall within that catagory. The method allows the loss coefficients and effux angles in any blade row to vary with gas flow conditions and the angle of incidence. The loss coefficients are assumed to be uninfluenced by Mach number. This assumption is unlikely to cause an appreciable error unless the blades involved have a high degree of curvature on the upper surface near the trailing edge.

B. Use of Dimensionless Parameters

In order to simplify the analysis and to present the complete per-

formance of any turbine graphically, the performance can best be determined using dimensionless parameters involving the different variables which influence turbine behavior. In this way the complete performance of a turbine under a variety of inlet conditons and speeds can be presented on three diagrams. The four main dimensionless parameters used were refered flow rate, refered rpm, overall pressure ratio, and a power coefficient. The conditions at any point in the turbine have been refered to inlet conditions. Ref. 4 presents a complete development of these parameters using Riabouchinski's theorem.

III. Description of the Turbine to be Analyzed

The turbine chosen for demonstration of the method and program was a small two stage axial flow turbine which was being evaluated for use in a space vehicle. It had proven unsatisfactory in the few preliminary tests conducted, due to low efficiency and power output. It was believed that poor agreement between test results and calculated flow quantities was due to inaccurate calculation of the required minimum flow areas between adjacent blades, and unrealistic assumptions of the loss coefficients. Small differences in blade thicknesses and blade angles between design drawings and the manufactured product can make large differences in the minimum flow areas.

Fig. 1 shows a 5:1 scale drawing of the meridinal blade passage of the turbine. Included on the drawing is the location of the local minimum flow areas and cross sections of the blades. Fig. 2 illustrates the system adopted for defining the geometry of a blade row and the gas angles relative to a blade row. Table I gives the dimensions and angles of the blades and other pertinent blade data. All blade data were obtained from Fig. 1 and the blade section drawings, Fig. 3 through 9. Not all of the blade section drawings are presented. Section drawings of the Stator and Rotor II are included to show the actual blade shapes, the minimum distance between blades, and to allow determination of the angles and dimensions at the mean blade height. Values for a, t, t_e, s, α^*, β^*, c, and A_e were obtained from the drawings for the mean diameter of each row of blades. Fig. 10 shows the blade angles for each row of blades and the turbine station designations.

The flow angle at the discharge of a blade row was determined from the empirical relation

$$\alpha_{exit} = \cos^{-1} \frac{a}{s - (t_e/\cos \alpha^*_{exit})}$$

This equation is widely used in Europe and the U.S.S.R. and is believed to be more accurate than the relation

$$\alpha_{exit} = \cos^{-1} \frac{a}{s}$$

commonly used in the United States. The sign convention used designates all gas angles positive if the tangential component of velocity is in the direction of rotor motion. It should be noted that the angle of incidence of the flow into the nozzle blade row is -42.5^{o}, Fig. 3. A modification of the nozzle blade design is contemplated which would reduce the angle of incidence to zero and reduce the losses. The trailing edges of the blades are relatively thick in order to prevent burn off at high temperature operation. All the blades converge to a minimum area shown on the blade section drawings. The area was determined by multiplying the average height of the minimum flow area between blades by the height of the blades.

Nitrogen gas was specified as the working fluid. The specific heat ratio for nitrogen is a function of temperature and varies from 1.372 to 1.347 over the temperature range of 780 to 1260^{o}F, Ref. 5, however the variation was considered small enough to allow an average value of 1.36 to be used in all calculations. The average value of the gas constant over the temperature range is 55.16 ft/^{o}R.

The design point of the turbine was reportedly 18,000 rpm and 1200 ^{o}F. In order to check this point, the operating characteristics of the turbine were investigated over the range of rpm between 10,000 and 19,000 at temperatures between 780 and 1260 ^{o}F.

IV. Development of Flow Function Formulas

In order to determine turbine performance for a given set of inlet and speed conditons, the course of an element of mass of gas was followed from

one blade row to the next, with calculations performed at each station. In this way the basic performance parameters were obtained for a given refered flow rate and refered rpm.

For steady adiabatic flow conditions the stagnation enthalpy along any streamline remains constant, both for absolute and relative flows. The mass flow rate for a given set of inlet conditions is constant and can be expressed by

$$\dot{w} = \frac{P_o A}{\sqrt{RT_o}} \sqrt{2g_c \gamma/(\gamma - 1)\left[(p/P_o)^{2/n} - (p/P_o)^{(n + 1)/n}\right]} \qquad (1)$$

The polytropic exponent was used in the power terms because the flow was adiabatic but not frictionless. See Appendix I.

Friction within a row of blades reduces the overall efficiency. In determining the flow rates with friction, the rate of flow is governed by the area of the minimum cross section. The flow area is reduced by the build up of the boundary layer along the profile from the leading edge to the point on the blade corresponding to the minimum cross section. The amount of boundary layer growth depends primarily upon the blade profile and the Reynolds number of the flow. In this paper the result of this reduction of flow has been termed a loss and designated ζ_e. This loss coefficient influences the flow rate and is believed to have more effect on the overall performance of a blade row than the total loss coefficient, ζ. The efficiency of a blade row can be expressed in terms of the temperature ratio dT/dT_{is} or ζ_e

$$\eta = dT/dT_{is} = 1 - \zeta_e \qquad (2)$$

The polytropic exponent can also be defined in terms of ζ_e

$$n = \gamma/(\zeta_e(\gamma - 1) + 1) \qquad (3)$$

The development of this expression is shown in Appendix I.

The mass flow rate can be expressed in the form of a nondimensionless flow function by rearrangement of Equation (1)

$$\Phi = \frac{\dot{w}\sqrt{T_o}}{P_o}\ \frac{\sqrt{R/g_c}}{A_e} = \sqrt{2\ \frac{\gamma}{\gamma-1}\left[\left({}^{1}/{}_{P_o/p}\right)^{2/n} - \left({}^{1}/{}_{P_o/p}\right)^{\frac{n+1}{n}}\right]} \qquad (5)$$

Since n is a function of the expansion loss incurred from entrance to the minimum area of the blade passage, Φ is a function of γ , ζ_e, and the pressure ratio P_o/p. For a given value of γ, a plot of Φ versus P_o/p will produce a curve as shown in Fig. 11 for each value of ζ_e. The data for a complete set of such curves for values of ζ_e from 0.0 to .25 and γ from 1.20 to 1.40 was obtained by Vavra using the CDC 1604 computor. The data for a specific heat ratio of 1.36 is given in Table IV. Using this data it is possible to determine values of P_o/p for calculated values of Φ by two way interpolation. The table is useful in manual calculations.

In order to adopt the flow function formula to a computor solution of the pressure ratio that would be accurate and minimize the time of computor utilization, it was necessary to calculate an approximate pressure ratio by expressing the terms in binomial series form. Substitution of the first two terms of the expansion in the equation for Φ was made in order to obtain $\Delta p/P_o$ as a function of n, γ, and Φ . As a first approximation $P_o/p = P_o/(P_o - \Delta p) = 1/(1 - \Delta p/P_o)$ or $p/P_o = 1 - \Delta p/P_o$. The complete development of the equation for the approximation

$$(P_o/p) = 1/(1 - n/3\ (\ 1 - \sqrt{1 - 3(\gamma - 1)/(\gamma(n - 1))\ \Phi^2}\ )) \qquad (6)$$

is given in Appendix I.

Using this approximate pressure ratio, a value of Φ could be calculated and compared with the known value of Φ . By increasing or decreasing the approximate pressure ratio by an increment as necessary, the value of P_o/p that corresponded to the known Φ could be obtained. This method of finding the pressure ratio corresponding to a given Φ was made into a subroutine called "Ratio" for the computor program.

V. Methods used in determining Loss Coefficients

In order to calculate the changes in the pressure and temperature from point to point through the turbine, it was necessary to establish the pressure losses that were involved. The overall pressure loss occuring in a blade row was subdivided into a number of component losses which are dependent upon various variables that define the aerodynamic form of the gas flow and the geometric form of the blade row. These losses are dependent upon the angle of incidence of the flow into the blade rows. The component losses considered were

a) Profile losses--losses due to skin friction which causes the build up of a boundary layer on the blade profile.

b) Secondary losses--losses resulting from non-uniformity of the three dimensional flow through a row of blades mainly caused by the interaction between the blade ends and the boundary layer on the annulus walls.

c) Tip clearance losses--losses due to leakage of gas over the ends of the blade tips.

d) Trailing edge mixing loss--a loss caused by the thickness of the trailing edge of the blades.

The profile losses were determined using the methods presented in Ref. 3. The profile loss for a given blade row is first determined for inflow at zero incidence. The stalling incidence of the blade row was then determined, stalling incidence being defined as the incidence at which profile loss is twice the loss at zero incidence. Profile losses at incidence other than zero were based upon the assumption that the ratio of profile loss at any incidence to profile loss at zero incidence is a function of the ratio of incidence to stalling incidence.

The profile loss coefficient at zero incidence was assumed to be a function of the discharge flow angle, the ratio of the blade angle to the discharge flow angle, the pitch to chord ratio, and the thickness to chord ratio. Ainley, Ref. 2, defines this loss coefficient as Y ≡ loss of total pressure divided by the total pressure at discharge minus the static pressure at discharge.

$$Y \equiv \frac{P}{P_1 - P_1} \equiv \frac{P}{q} = \frac{P}{\rho/_2 \, V^2} \qquad (7)$$

For this equation to be valid the total pressure at exit would have to be measured far downstream of the blade row. The pressure would also have to be an average value. The total pressure at discharge in the immediate vicinity of the trailing edge of the blade is known to fluctuate. It was considered more correct to express this loss coefficient in terms of Δh_{is} rather than in terms of $\Delta P/(\rho/_2 V^2)$.

Using the differential form of the Energy Equation, where $dq = 0$ for isentropic flow, the loss of a blade row can be expressed in terms of Δh

$$dq = du + p\ dv = dh - v\ dp = 0$$

$$dh = v\ dp = RT\ dp/p = dp/\rho$$

$$\text{or} \qquad \Delta h = \Delta p/\rho$$

Substitution of the expression $\rho\Delta h$ for Δp in Equation (7) gives

$$Y = \frac{\rho \Delta h}{\frac{\rho/_2 V^2}{gJ}} = \frac{\Delta h}{\frac{V^2}{2gJ}} \quad \text{where} \quad \frac{\Delta h}{\frac{V^2}{2gJ}} \approx \frac{\Delta h'}{\frac{V^2}{2gJ}} \approx \frac{\text{Loss}}{\frac{V_{is}^2}{2gJ} - \text{Loss}}$$

as shown by Fig. 12. The right and left sides of the equation are not exactly equal since the temperature at inlet to a blade row is not the same as at the exit. However this difference is so small for an individual blade row that it can be considered insignificant.

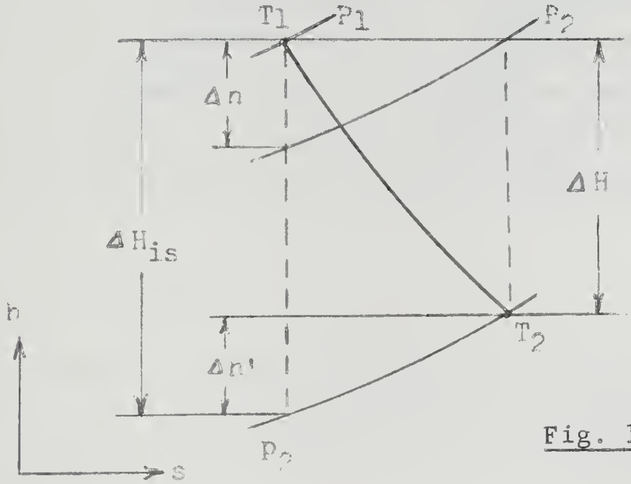

Fig. 12.

Expansion Process for a Blade Row

By rearrangement

$$Y \frac{V_{is}^2}{2gJ} \approx (1 + Y) \text{ Loss} \quad \text{or Loss} = \left(\frac{Y}{1 + Y}\right) \frac{V_{is}^2}{2gJ} \qquad (8)$$

and $\frac{Y}{1 + Y}$ can be considered a new loss coefficient, ζ .

The imperical equations for determination of Y_p, Y_s, and Y_k at zero incidence were obtained from Ref. 6 and are presented in Appendix II. Complete calculation for the loss coefficients of the Nozzle and Rotor I are also presented in Appendix II. The calculations for the loss coefficients for the Stator and Rotor II are similiar to those for the Nozzle and Rotor I respectively. Variations of the losses with gas inlet angle to a blade row at large positive and negative incidences are uncertain, but according to Ainley, Ref. 6, reasonable correlation of test and calculated turbine performance has been obtained by restricting the use of the equation for Y_s and Y_k to the range of $-1.5 \leq i/i_s \leq 1.0$. At values of $i/i_s > 1.0$ the secondary and clearance loss coefficients should be assumed constant and equal to the value when $i/i_s = 1.0$. Similiarly when $i/i_s < -1.5$ the values of Y_s and Y_k equal to those obtained for $i/i_s = -1.5$ should be used.

The profile loss coefficient Y_p for conventional section blades at zero incidence can be obtained from Fig. 13. Values of positive stalling incidence of cascades are shown in Fig. 14. The variation of profile loss with incidence is given in Fig. 15. Using the curves presented in these Figures, all of which were reproduced from Ref. 3 and 6, values of ζ_p at ten degree intervals of incidence angle were determined and are presented for each blade row in Tables V, VI, and VII in Appendix II.

In determining the secondary loss coefficients Ainley made the basic assumption that

$$C_{Ds} = \lambda C_L^2/(s/c)$$

where λ is primarily dependent upon the degree of acceleration imparted to the gas as it flows through a blade row. A similiar assumption was made in regard to the tip clearance loss coefficients in stating that the drag coefficient can be expressed by

$$C_{Dk} = \text{Constant } (k/h) \; C_L^2/(s/c)$$

The value of λ used in determining Y_s was obtained from Fig. 16. It should be noted that secondary and tip clearance losses in a blade row having fixed inlet and outlet gas angles are independent of s/c, thus optimum pitching of a row of blades is obtained using the pitch that gives the minimum profile loss.

The equations presented in Ref. 6 for calculation of the trailing edge loss were purely theoretical and were not considered to be as accurate as the equation

$$\zeta_{te} = \frac{3\ te/a}{\sum \delta^*/a}\ \zeta_p \tag{9}$$

developed by Markov, Ref. 7, using average measured values of the shape parameters. Vavra, in an as yet unpublished paper, Ref. 8, explains the development of equations for ζ_e and $\sum \frac{\delta^*}{a}$. The assumption that the boundary layer thickness is the same at the throat as at the trailing edge was made, Fig. 17.

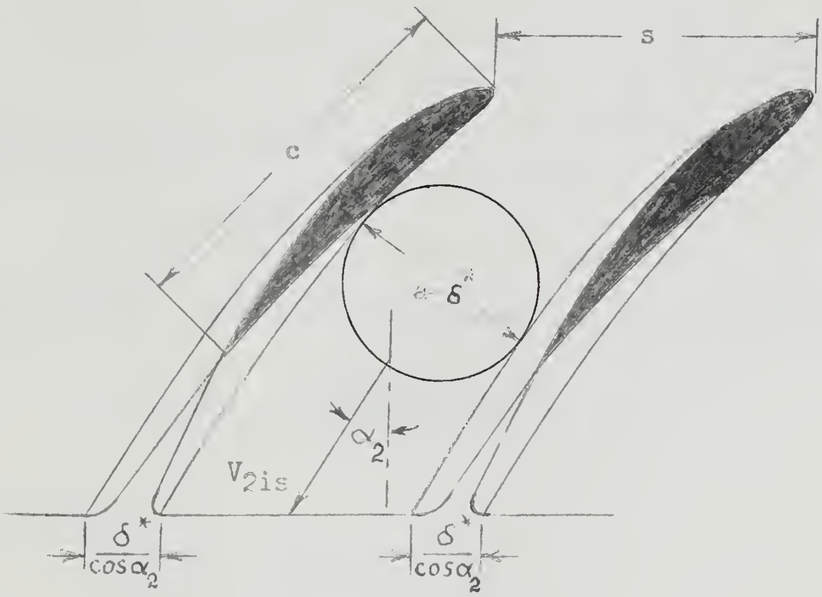

Fig. 17

Boundary Layer Thickness Diagram

Such an assumption would mean that further expansion of the boundary layer between the minimum cross sectional area and the trailing edge does not take place. $\sum\delta^*$ has been defined as the sum of the displacement thicknesses of the boundary layers on both sides of a profile at the trailing edge of the blades. The flow rate was expressed as

$$\dot{w} = \rho_2 A_2 V_2 = \rho_2 V_2 (a - \sum\delta^*) = \rho_2 V_2 (1 - \frac{\sum\delta^*}{a})\ a$$

or $$\dot{w} = \rho_{2th} V_{2th} A \nu$$

where ν is a factor which accounts for the reduction in the flow area at the minimum cross-section of the flow passage between blades. Vavra developed a theoretical expression for ζ_e from curves of $\frac{\zeta_e}{1 - \nu^2}$ versus the pressure ratio across a blade row.

$$\frac{\zeta_e}{1 - \nu^2} = f\left(\frac{P_{inlet}}{P_{discharge}}\right)$$

For a γ of 1.36

$$\zeta_e = .9\ (1 - \zeta_p^{\ 2}) \tag{10}$$

Energy thickness was defined as

$$H^{***} \equiv \frac{\zeta^{***}}{\zeta^*}$$

and a value of $H^{***} = 2.2$ was given in Ref. 7. $(1 - \zeta_p)$ was expressed as

$$(1 - \zeta_p) = \frac{1 - H^{***}\sum\delta^*/a}{1 - \sum\delta^*/a}$$

Upon rearranging terms

$$1 - \sum\delta^*/a = \frac{H^{***} - 1}{H^{***} - 1 + \zeta_p}$$

from which the following equations were obtained

$$\nu = \frac{1.2}{1.2 + \zeta_p} \tag{11}$$

$$\sum \delta^* / a = \frac{\zeta_p}{1.2 + \zeta_p} \tag{12}$$

These equations were utilized in calculation of the trailing edge loss and the reduction in flow area due to the build up of the boundary layer along the profile from the leading edge to the throat of the blades.

The values of the total loss coefficients given in Tables IV through VI are for the design tip clearance of .033 in. for Rotor I and .021 in. for Rotor II. These clearances are reduced when operating at elevated temperatures. Since it is impossible to say exactly what the clearances are at the operating temperatures, loss curves were also drawn for tip clearances of .005, .010, .015, and .020 in. The loss curves for each blade row are presented graphically in Fig. 18, 19, and 20.

VI. Development of Basic Equations

The equations used in calculating the state of the flow at a given point in the passage through the turbine were based upon the equations for absolute and relative flows. These equations have been fully developed in Ref. 1 from the basic Equation of Motion, Equation of Continuity, and the steady flow Energy Equation. For steady adiabatic absolute flows through stationary blade rows the total enthalpy along a particular streamline is constant. Likewise for steady adiabatic relative flows through moving blade rows the total relative enthalpy along a relative streamline is constant. Expressed in terms of velocities and static enthalpies

$$H = h + \frac{V^2}{2} + gz \tag{13}$$

for absolute flows and

$$H_R = h + \frac{W^2}{2} - \frac{\omega^2 R^2}{2} + gz \tag{14}$$

for relative flows. The effect of the gz term has been considered negligible. Ref. 1 also explains in detail how Euler's Turbine Equation

$$\Delta H = C_p \, \Delta T_w = \frac{U_1 \, V_{u1} - U_2 \, V_{u2}}{g \, J}$$

can be developed either by combining the enthalpy equations for absolute and relative flows between two points or from the general Momentum Equation. While this relation has not been included in the computor program, it can be used as a check on the solution of the total enthalpy drop through the turbine if manual calculations are attempted.

The equations used in the computor program were developed and arranged so that calculations would be repetitive for any number of stages. The nozzle was considered to be the same as any other stationary blade row except that the velocity vector of the inlet flow was considered to be axial in direction. For each blade row the absolute velocity, relative velocity in the case of rotor blade rows, was first determined using the losses obtained from a knowledge of the inlet flow. The temperature at discharge from a blade row could be calculated from this velocity. Also the velocity triangle can be drawn if the velocity and angle of the inflow are known. For each blade row the flow function method was used to find the pressure ratio across it. All losses were considered in percent of the theoretical kinetic energy at discharge from a cascade. All pressures at inlet to a blade row were expressed as a ratio of the total pressure at that point to the pressure at inlet to the turbine.

A form of the basic equation for steady adiabatic flow was formulated whereby an equivalent temperature and pressure at the minimum area of the blade passage was determined. The flow function could then be expressed as

$$\Phi = \frac{\dot{w}\sqrt{T_o}}{P_o} \quad \frac{\sqrt{T_{eq}/T_o}}{P_{eq}/P_o} \quad \frac{R}{g_c A_e} \tag{16}$$

where A_e was the minimum flow area for the cascade.

A. Nozzle and Stator

The equations for calculation of the thermodynamic flow process occuring in the Nozzle or Stator are based upon the fact that the total enthalpy along a streamline is constant. For steady adiabatic flow, the enthalpy drop at constant entropy can be expressed as

$$\Delta h_{is} = \frac{V_{1is}^2}{2gJ} = \Delta h_{actual} + (\text{loss coefficient x } \Delta h_{is})$$

or in terms of velocities

$$\frac{V_{1is}^{2}}{2gJ} = \frac{V_{1}^{2}}{2gJ} + \zeta_N \frac{V_{1is}^{2}}{2gJ} \tag{17}$$

Since $h = C_p T$, the relationship can also be expressed as

$$\Delta T_{is} = \Delta T_{actual} + \zeta_N \Delta T_{is} \tag{18}$$

and shown graphically in Fig. 21.

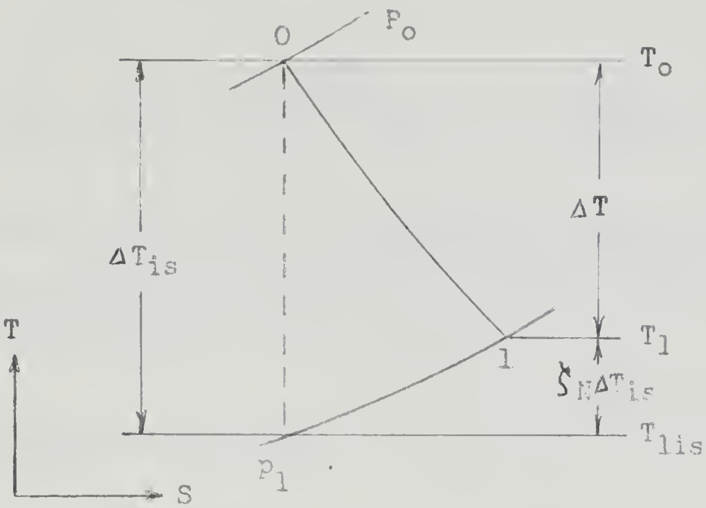

Fig. 21

Temperature Change for a Blade Row

The velocity at the discharge of a stationary row of blades was determined from the following relations

$$\frac{V_1^2}{2gJ} = \Delta h = \Delta h_{is} - \zeta_N \Delta h_{is}$$

$$= C_p \Delta T = C_p (\Delta T_{is} - \zeta_N \Delta T_{is})$$

$$= C_p \Delta T_{is} (1 - \zeta_N) \tag{19}$$

ΔT_{is} can be expressed in terms of pressure ratio

$$\Delta T_{is} = \left[1 - \left(\frac{P_1}{P_o} \right)^{\frac{\gamma - 1}{\gamma}} \right] T_o$$

When a substitution for ΔT_{is} is made

$$\frac{V_1^{\,2}}{2gJ} = (1 - \zeta_N)\, C_p\, T_o \left[1 - \left(\frac{P_1}{P_o} \right)^{\frac{\gamma - 1}{\gamma}} \right]$$

For simplicity and ease of calculations all velocities were divided by 100, so

$$\left(\frac{V_1}{100} \right)^2 = 5.007\, (1 - \zeta_N) \left[1 - \left(\frac{P_1}{P_o} \right)^{\frac{\gamma - 1}{\gamma}} \right] C_p\, T_o = 5.007 \frac{R\gamma}{J(\gamma - 1)}\, T_o (1 - \zeta_N) \left[1 - \left(\frac{P_1}{P_o} \right)^{\frac{\gamma - 1}{\gamma}} \right] \quad (20)$$

When the pressure ratio p_1/P_o, corresponding to the value of the flow function Φ_N is substituted into Equation (20) the value of V_1 can be calculated. The equation is in the form of

$$\left(\frac{V_1}{100} \right)^2 = \text{constant}\ (1 - \zeta_N)\ \Delta T_{is}$$

Since $T_o - T_1 = (1 - \zeta_N) \Delta T_{is}$

$$\left(\frac{V_1}{100} \right)^2 = \text{constant}\ (T_o - T_1) \quad (21)$$

Equation (21) was used to determine the temperature at station 1.

B. Rotor

All values of the velocity triangle representing flow conditions at inlet to a rotor blade row, Fig. 22, can be calculated when the peripherial speed of the rotor blades, the absolute velocity of the inlet flow, and the angle of incidence are known.

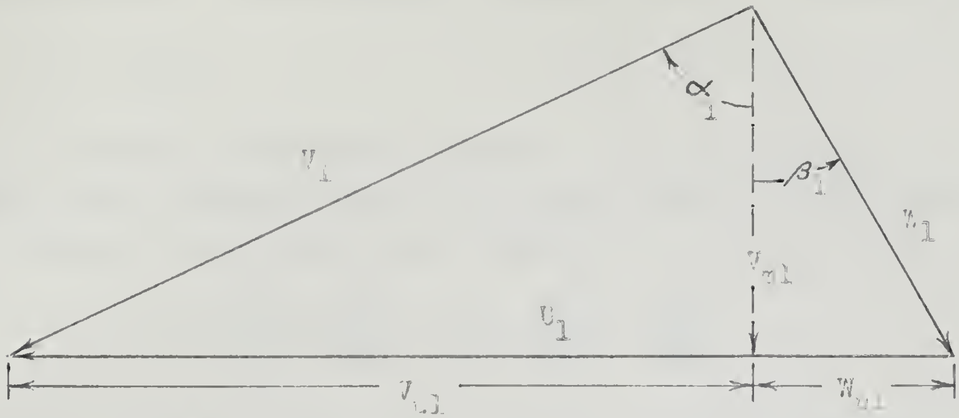

Fig. 22

Velocity Triangle, Rotor Inlet

The following equations allow ease of calculation of the magnitude and direction of the vectors.

$$V_{u1} = V_1 \sin \alpha_1$$

$$V_{m1} = V_1 \cos \alpha_1$$

$$W_{u1} = V_{u1} - U_1$$

$$W_1^{\ 2} = V_{m1}^{\ 2} + W_{u1}^{\ 2}$$

$$\beta_1 = \tan^{-1}(W_{u1}/V_{m1})$$

If the loss curves for the first rotor are entered with the inlet flow angle β_1, the losses ζ_R and ζ_{eR} can be obtained. In order to find the static pressure after the rotor the flow function must be based upon relative flow relations. In the rotating blade rows the relative total enthalpy must remain constant along a given relative streamline

$$H_R = h + \frac{W^2}{2gJ} - \frac{U^2}{2gJ} = \text{constant} \qquad (22)$$

Since the radius of the mean flow path at rotor entrance differs from that at rotor exit, there will be significant difference in the peripheral speed at these two points. The peripheral speed at a point is given by the relation

$$U = \pi ND/720$$

where the diameter is measured in inches.

The total enthalpy at inlet to the rotor blade row is the same as the total enthalpy at the minimum area, therefore

$$h_1 + \frac{W_1^{\,2}}{2gJ} - \frac{U_1^{\,2}}{2gJ} = h_2^{*} + \frac{W_2^{\,*}}{2gJ} - \frac{U_2^{\,2}}{2gJ}$$

The sum of h_2^{*} and $W_2^{2*}/2gJ$ can be considered to be an equivalent enthalpy, $H_{eq.}$, similiar to the sum of h and $V^2/2gJ$ for a stationary row of blades. When the variation in the peripheral speed is taken into consideration

$$H_{eq.} = h_1 + (W_1^{\,2} + U_2^{\,2} - U_1^{\,2})/\ 2gJ \tag{23}$$

The equivalent enthalpy can also be expressed as $C_p\ T_{eq.}$. An equation for determination of the equivalent temperature can be derived by dividing Equation 23 by C_p

$$T_{eq.} = T_1 + (W_1^{\,2} + U_2^{\,2} - U_1^{\,2})\ 2gJC_p \tag{24}$$

The equivalent total temperature and pressure at inlet to the rotor was designated T_R and P_R respectively. In ratio form

$$P_{R1}/P_1 = (T_{R1}/T_1)^{\frac{\gamma}{\gamma-1}} \tag{24}$$

The flow function for the rotor can be written as

$$\Phi R = \frac{\dot{w}\sqrt{T_{R1}}}{P_{R1}} \sqrt{\frac{R}{g_c}}\ \frac{1}{A_e}$$

where A_e is the area at the minimum flow cross section. By refering all temperatures and pressures to turbine inlet conditions, a nondimensional

equation is obtained for the flow function

$$\Phi_R = \frac{\dot{w}\sqrt{T_o}}{P_o} \quad \frac{\sqrt{T_{R1}/T_o}}{P_{R1}/P_o} \quad \frac{\sqrt{R/gc}}{A_e} \tag{25}$$

The relative velocity after the rotor can be expressed as

$$\frac{W_2}{2gJ} = h_1 + \frac{W_1^2 + U_2^2 - U_1^2}{2gJ} - h_2$$

or $$\frac{W_2}{2gJ} = C_p\, T_1 + \frac{W_1^2 + U_2^2 - U_1^2}{2gJ} - C_p\, T_2$$

$$= C_p\, (T_{eq} - T_2) \tag{26}$$

also $$\frac{W_2}{2gJ} = (1 - \zeta_R)\, \Delta T_{is} \tag{27}$$

These relations are presented graphically in Fig. 23.

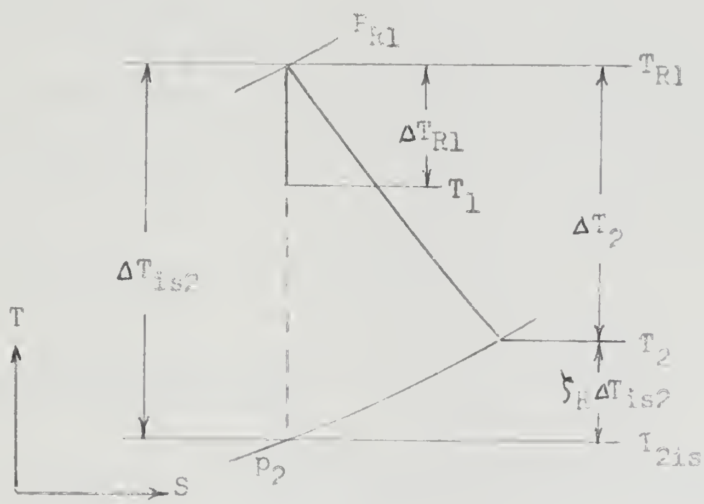

Fig. 23

Temperature Change for a Rotor Blade Row

The velocity triangle representing flow conditions at exit from the rotor blade row can be determined from the peripheral speed, the relative velocity, and the angle of exit, Fig. 24.

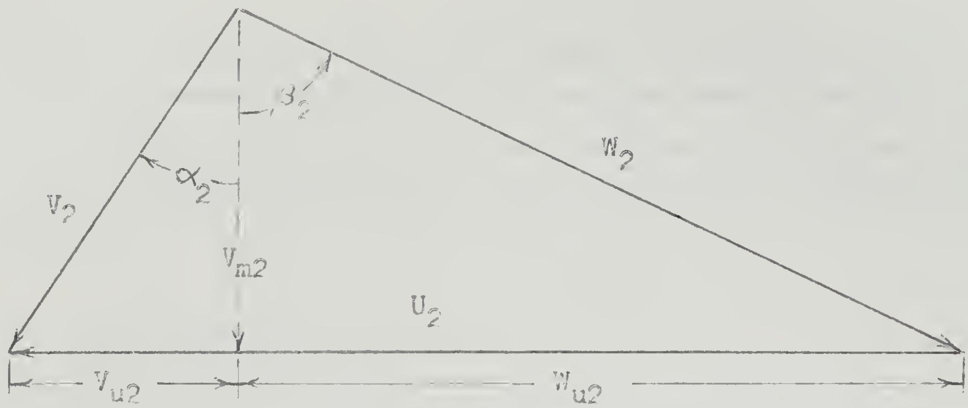

Fig. 24

<u>Velocity Triangle, Rotor Exit</u>

The equations involved are

$$W_{u2} = W_2 \sin \beta_2$$

$$V_{m2} = W_2 \cos \beta_2$$

$$V_{u2} = U_2 - W_{u2}$$

$$V_2^{\,2} = V_{m2}^{\,2} + V_{u2}^{\,2}$$

$$\alpha_2 = \tan^{-1} (V_{u2}/V_{m2})$$

The pressure ratio P_{S2}/P_o at entrance to the next stator blade row can be calculated

$$\frac{P_{S2}}{P_2} = (T_{S2}/T_2)^{\frac{\gamma}{\gamma - 1}}$$

$$\frac{P_{S2}}{P_o} = \frac{P_{S2}}{P_2} \times \frac{P_2}{P_o}$$

The procedure outlined above can be repeated for as many stages as necessary depending upon the turbine design. Fig. 25 is a complete T - S diagram representative of the two stage turbine considered. Sample calculations are presented in Appendix IV.

C. Diffusor

For stationary gas turbine power plants an efficiency for the Diffusor of 70% is commonly accepted for a flow that departs axially from the last row of blades. For a flow that is discharged from the last blade row at an angle to the axial direction, the actual diffusor efficiency was considered to be

$$\eta_A = \eta_D \, (\cos \alpha)^2$$

The overall turbine efficiency was defined in terms of enthalpy

$$\eta_T = \frac{\Delta H}{\Delta H_{is}} = \frac{\Delta T_w}{\Delta T_{is}}$$

Defining turbine efficiency in this way accounts for recovery factors.

The ability of the diffusor to transform the kinetic energy of the flow at exit from the last blade row is a function of the efficiency of the diffusor and the difference between the kinetic energy of the flow at inlet to and discharge from the diffusor. In terms of temperature change, this relationship can be expressed as

$$\Delta T_{recovery} = \eta_D \left(\frac{V_{m2}^{\,2} - V_D^{\,2}}{2gJ\, C_p} \right)$$

where the velocity of discharge was calculated using the Continuity Equation

$$\dot{w} = \rho_D \, A_D \, V_D = \text{constant}$$

$$V_D = \frac{\dot{w} \, RT_4}{A_D \, P_4}$$

By summing the work output of the individual stages the overall work of the turbine was obtained. The specific work output of the turbine is equal to the enthalpy change Δ H between the inlet to the first blade row

and the discharge from the last blade row. For the two stage turbine considered

$$\Delta H_w = (U_1 V_{u1} - U_2 V_{u2})/gJ + (U_3 V_{u3} - U_4 V_{u4})/gJ = C_p \Delta T_w$$

The power output was desired in coefficient form. Since the power can be expressed as the mass flow rate times the enthalpy change, a suitable coefficient form is

$$\lambda = \frac{\dot{H}\dot{P}}{P_o\sqrt{T_o}} = \frac{\dot{w}\sqrt{T_o}}{P_o} \; C_p \; \frac{\Delta T_w}{T_o} \; 1.055 \left(\frac{KW}{psia\sqrt{{}^oR}}\right) \tag{27}$$

where $\Delta T_w = (H_o - H_4)/C_p = T_o - T_{s4}$.

The overall pressure ratio of the turbine was determined by first calculating the ratio of the total pressure at discharge from the diffusor to the static pressure at entrance to the diffusor.

$$P_e/p_4 = (T_e/T_4)^{\frac{\gamma}{\gamma-1}} = \left(\frac{T_4 + \Delta T_{is\ D}}{T_4}\right)^{\frac{\gamma}{\gamma-1}} \tag{28}$$

Using the pressure ratio across the turbine blade rows, P_o/p_4, the overall pressure ratio was calculated

$$\frac{P_o}{P_e} = \frac{P_o}{p_4} \times \frac{p_4}{P_e} \; . \tag{29}$$

The isentropic temperature drop through the turbine could be found using the relation

$$\frac{\Delta T_{is}}{T_o} = \left(\frac{P_o - P_e}{P_o}\right)^{\frac{\gamma-1}{\gamma}}$$

Turbine efficiency can be computed using the definition

$$\eta_T = \frac{\Delta H_w}{\Delta H_{is}} = \frac{\Delta T_w}{\Delta T_{isT}}$$

In order to compute the overall velocity ratio of the turbine the mean average diameter of the flow passage of the turbine was calculated. Since the theoretical velocity C_o for isentropic expansion from a stagnation pressure at turbine entrance to the static pressure at turbine discharge could be expressed as

$$C_o = \sqrt{2gJC_p \Delta T_{isT}}$$

an equation for the velocity ratio was

$$\frac{U_{avg.}}{C_o} = \frac{\pi N D_{avg.}}{720 \sqrt{2gJC_p \Delta T_{isT}}}$$

VII. Computor Program

A. General

The Control Data Corporation 1604 digitial computor at the U.S. Naval Postgraduate School was utilized to provide rapid and accurate solutions to the turbine performance equations. The source program was written in the most basic and familiar version of Fortran language so that the program would be compatible with other models and makes of computors. In order to clearly document and visually present the step by step procedures of the program, flow charts were drawn for the main program and the major subroutines. The flow charts and selected versions of the basic program are presented in Appendix III. Transfers of control and test routines are shown more clearly by flow charts than if described in words. A table of Fortran names, equivalent symbols, and meanings is also presented in Appendix III.

B. Main Program

The complete Fortran program was a composite of a main program and several sub-programs. The main program was used for control and input-output, while the subprograms performed the repetative calculations. Input data such as turbine blade row dimensions, blade angles, and loss coefficients were placed in one dimensional arrays. All constants and variables which were required in the main program and one or more sub-programs were included in a Common statement so that communication between the main program and sub-programs was possible. The values of diffusor cross sectional area, average mean flow diameter, specific heat ratio and gas constant for the working

fluid were considered constant and initialized in the main program for use in all sub-programs.

Only the parameters necessary to demonstrate the performance of the turbine and allow development of the performance maps were normally printed out for each combination of refered rpm and refered flow rate. The parameters most representative of turbine performance were refered rpm, refered flow rate, efficiency, power coefficient, overall pressure ratio, and speed ratio. Of course the print out of the solution to every equation was possible. Such a print out was made for the test case, Appendix IV.

The performance of the two stage turbine considered in this paper was desired over the temperature range from 1240 to 1720 ^{o}R and the speed range from 10,000 to 19,000 rpm. The resulting range of refered rpm was 240 to 540. A "Do" loop was inserted which allowed calculations to be made at any desired interval over the range. For ease of plotting and completeness of coverage, an interval of 50 was initially chosen and later reduced to 10. The performance maps show only the curves for refered rpms of 240, 290, 340, 390, 440, 490, and 540 in order to allow curve separation and prevent confusion, however the smaller interval was necessary in order to accurately complete the performance maps. In order to compare the theoretical computations with actual test results a single refered rpm was programed so that the Do loop would start and stop on the same value. The computor time for calculation of one test run was approximately one minute and ten seconds, compared to two minutes and fifty eight seconds for complete coverage of the refered rpm range using an interval of 10.

The performance of the turbine was desired at all values of refered flow rate between zero and that value which would cause a turbine blade row to choke. Although the flow rate Do loop was programed to start at .1 and continue to 5.0 in steps of .1 or .01, the inflow angles to the blade rows were so great at the lower values of refered flow rate that the range of angles over which the loss curves were valid was exceeded until a flow rate of approximately 2.5 was reached. The range of the Do loop was reduced by starting at a value of 2.0 in order to reduce the computor time involved. A flag, ICR or IBR, was set to test whether the angles exceeded $\neq$ or - 70^{o}. If the flow angle was excessive at inlet to either the rotor or stator blade rows, computations at that refered flow rate were stopped and the Do loop

continued. The turbine was found to choke before a refered flow rate of 4.0 was reached. Of course the point of choking will vary from one turbine design to another depending upon the dimensions of the blade rows and the losses. A sufficiently high upper limit should be chosen for the Do loop so that choking would occur prior to completion of the Do loop.

The flow function for each blade row was computed and compared with the maximum value of the flow function corresponding to the critical pressure ratio. If the maximum was exceeded, the name and number of the blade row was printed out and calculations at a new refered rpm was initiated. If the maximum value of the flow function was not exceeded in any blade row, the calculation of the performance parameters was completed and the answers printed.

C. Subroutines for Stator and Rotor

Frequency occuring constants and exponents used through out the program were computed in function sub-programs. All other computations were made in subroutines Stator, Rotor, Diffusor, and Ratio. As shown by the flow charts, the form of the subroutines for the stator and rotor are quite similiar. The inlet flow angle was utilized to obtain the loss coefficients for a particular blade row. Since the loss coefficients were picked from the loss curves at ten degree intervals and presented as a one-dimensional array, interpolation for intermediate values of the inlet flow angle was necessary. This interpolation was accomplished by subtracting the value of the inlet flow angle from 70^{o} and dividing by the 10^{o} interval. The quotient must be added to 1.0. The angles must be expressed in radians for all computor calculations. A change from floating point to fixed point arithmetic caused truncation of the result to a whole number equal to or greater than 1.0. By obtaining the difference between the floating point and fixed point values, linear interpolation between the closest given values of the loss coefficients could be made. This method of interpolation was believed to be sufficiently accurate over the range of angles for which loss coefficients were calculated, since the percent error of the loss coefficients was not known.

D. Subroutine for Determination of Pressure Ratio

In order to obtain the pressure ratio across a blade row a separate and rather complicated system of tests and calculations was necessary. A

subroutine called Ratio was formed. The value of the polytropic exponent was calculated and used to find the critical pressure ratio for a given blade row. The critical pressure ratio was substituted in Equation 5 and the value for the maximum flow function existing at the critical pressure ratio was determined. The calculated value of the flow function was compared with the maximum value and if the maximum was exceeded, the blade row was choked and a return statement would transfer control back to the main program.

In order to find the pressure ratio corresponding to a given value of the flow function obtained from Equation 5, an approximate value of the pressure ratio was computed using Equation 6. The approximate value was tested to determine whether it was greater or less than the critical pressure ratio. If the approximate pressure ratio was greater than the critical, .05 was subtracted from the initial value and the new approximate value, which would be less than critical, was used. If the approximate value was not greater than the critical value, the approximation was increased or decreased in steps of .0001 as necessary, and a trial value of the flow function calculated and tested at each step. As soon as the known value of the flow function was bracketed, the last value of the approximate pressure ratio was considered sufficiently accurate to use as the pressure ratio corresponding to the value of the flow function. In the case of manual calculations, the pressure ratio could be obtained from Table III by making a two way interpolation. The use of logarithms was required in order to achieve the necessary accuracy. Since only subsonic flow has been considered, all pressure ratios will be less than the critical pressure ratio.

A flow chart of Subroutine Diffu (Diffusor) is not presented since no control transitions or conditional statements were involved. Only a straight forward step by step solution of the equations is required.

VIII. Turbine Analysis

A. Preliminary Analysis based upon Design Drawings

In order to demonstrate the application of the method and the usefulness of the computor program, 15 different computor runs were made. A list of the runs is given in Table VIII, Appendix V, which shows the refered rpm, specific heat ratio, gas constant, rotor tip clearance, and

blade flow angles of each of the runs. Print outs of the results of the runs are given in Appendix V.

The turbine had been designed to run at 18,000 rpm and 1200 $^{\circ}F$ using Nitrogen gas as the working fluid. Since the test data presented in Table II and III were not available at the time of completion of the programming of the equations for computor solution, a series of computor runs were made using flow areas and rotor tip clearances based upon design data and the blade drawings.

Exactly how much the rotor tip clearance and corresponding flow areas change with changes in temperature depends upon the design and the materials, and cannot be determined except by extensive testing. It was assumed that the high temperature of 1200 $^{\circ}F$ would cause both rotor tip clearances to be reduced, since some thermal expansion of the rotor blades and walls would take place. The turbine design indicated that the reduction of the clearance of the first rotor would be greater than that of the second, therefore the clearance of each rotor blade row was assumed to be the same at high temperature operating conditions. .

1. Test Runs at Design Refered RPM

The first four runs were made at design refered rpm using Nitrogen as the working fluid. The clearances and areas measured from the drawings were used for Run #1. The rotor tip clearances of .033 and .021 were reduced to .015, .010, and .005 for runs number 2, 3, and 4 respectively. The reduction of the tip clearances caused a corresponding reduction in the flow areas as shown in Table VIII.

A plot of refered flow rate versus pressure ratio was made, Fig. 33, using the results of these runs. The plot showed that the pressure ratio required for a given flow rate increases as the clearances decrease.

2. Development of Maps and Indicated Turbine Performance

Based upon the very limited information available, a rotor tip clearance of .015 was believed to be the best approximation of the actual clearance that would occur during operation. This clearance was assumed to exist over the range of refered rpm from 240 to 540. For Run #5 the computor was programed to compute the performance parameters over the complete range of refered rpm at intervals of 10. The refered flow rate covered the range from 2.0 to choking in steps of .1. Since a relatively large increase

in pressure ratio is required to produce a small increase in refered flow rate as the pressure ratio corresponding to choked conditions is approached, an additional run, #6, was made over the same range of rpm, but over a reduced range of refered flow rate starting at 3.7 and increasing in steps of .01. The performance parameters corresponding to flows near choking were more accurately determined yet the data output and computor time involved was not excessive.

The complete set of performance maps, Fig. 26 through 32, were drawn using the results of runs #5 and #6. Although the data input to the computor was based solely upon the design information and an assumed rotor tip clearance, a general overall prediction of turbine performance can be made. This estimation could be refined when actual measurements of the blades and clearances were made.

The three most important graphs of this set are Fig. 26, 27, and 28. From these maps all of the parameters which are needed to completely define turbine performance can be obtained if any two parameters are known or assumed. Turbine efficiency and power coefficient corresponding to given values of pressure ratio and refered rpm are presented in Fig. 26. The refered flow rate can be obtained from Fig. 27. The velocity ratio corresponding to the efficiency and pressure ratio of the operating conditions can be determined from Fig. 28.

In order to draw the curves of constant pressure ratio and efficiency in Fig. 26, plots of power coefficient versus turbine efficiency, Fig. 29, and power coefficient versus pressure ratio, Fig. 30, were made. The data sheets for run #6 were also consulted in order to determine accurately the curves of constant efficiency for .780 and .784.

From Fig. 26 it can be seen that turbine efficiency is a maximum of .784 at the design refered rpm of 441.8 and a pressure ratio of 2.69. The power coefficient corresponding to these condtions is .189. The effects of changes in either the pressure ratio or the refered rpm upon turbine efficiency can be clearly seen on this map.

A refered flow rate of 3.72 was obtained from Fig. 27 for the design refered rpm of 441.8 and the pressure ratio of 2.69. Fig. 27 shows that the pressure ratio changes for a given refered flow rate with changes in the refered rpm. This effect upon pressure ratio is more pronounced at the

lower values of rpm. The refered flow rate and pressure ratio at which choking occurs for a given refered rpm is shown by the point of termination of the upper ends of the curves.

Fig. 28 shows the velocity ratio corresponding to pressure ratio and turbine efficiency. This map was developed from plots of velocity ratio versus pressure ratio, Fig. 31, and turbine efficiency versus pressure ratio, Fig. 32. The curves of constant pressure ratio in the figure show that the operation of the turbine will be restricted to a fairly narrow range with the maximum efficiency occuring at a velocity ratio of .445 for a pressure ratio of 2.69. This plot also shows that the efficiency varies very little until pressure ratios too low to be used in normal operation are reached.

B. Performance of Turbine with Redesigned Nozzle Blades

The manufacturer had indicated that the nozzle blades would be redesigned so that the flow would enter the nozzle blade row at zero incidence. Such a redesign would reduce the losses in the nozzle which were at present excessive due mainly to the large negative angle of incidence. The flow areas of the Nozzle, Rotor I, and Rotor II were to be reduced to 8.28, 9.38, and 14.20 sq. in. The planned modification would reduce the loss coefficients ζ_e and ζ_N from .2050 and .2475 to .0828 and .1364 respectively.

Run #7 was made using the areas and loss coefficients for the modification so that a comparison between the turbine performance of the original design and that of the redesign could be made. A plot of refered flow rate versus pressure ratio for this run was included in Fig. 33. From a comparison of the printout of Runs #7 and #3, it can be seen that turbine performance would be improved by the redesign. The maximum efficiency would be increased from .791 to .819.

C. Attempted Correlation of Test Data and Program Predicted Performance

When the open cycle test data presented in Tables II and III were received from the manufacturer, several computor runs were made at the same refered rpm as the tests in an attempt to correlate the theoretical results and the test data. There was insufficient time for a complete comparison to be made. A complete set of performance maps was not drawn in each case, only a plot of refered flow rate versus pressure ratio was made.

The test data presented in Table II was obtained by the manufacturer from open cycle tests using air as the working fluid and methyl alcohol as a fuel for in-line combustion. The turbine inlet temperature and rpm were slightly lower than the design values and resulted in a refered rpm of 420.9. The pressure ratio across the turbine was 2.347. The mass flow rate was taken as the sum of the fuel and air flow rates and was 3.44 lbs/sec. The corresponding refered flow rate was 3.925.

In order to determine the specific heat ratio and gas constant of the flow, the combustion gases were considered to be the products of the complete combustion of methyl alcohol and air. Sample calculations of the specific heat ratio and the gas constant are presented in Appendix I.

The manufacturer had measured the actual minimum flow areas of the blades assuming that a rotor tip clearance of .020 existed when the turbine was operating. The measured areas were different from those obtained from the original drawings. The measured areas are listed in Table II.

Runs #8, 9, and 10 were made using loss coefficients and flow areas corresponding to rotor tip clearances of .010, .015, and .020 in. respectively. A plot of refered flow rate versus pressure ratio, Fig. 34, was made from which it could be seen that the measured flow rates for a given pressure ratio were greater than the theoretical at all three values of tip clearance, and that either larger clearances or flow areas existed in the operating turbine.

Runs #11, 12, and 13 were made using a refered rpm of 407.4 which corresponded to the temperature and speed of Test II. The refered flow rate determined from the test data was 3.995. Due to the simularity of the conditions for Test I and II the curves of refered flow rate versus pressure ratio shown in Fig. 34 plotted very close to those for the higher rpm of 420.9.

Additional test data was received from the manufacturer as the open cycle tests were completed. The refered flow rate and pressure ratio of each test was calculated and plotted in Fig. 34 resulting in a scatter of test points through which a single average curve was drawn for comparative purposes. The curve indicated that greater flow rates for given values of pressure ratio actually occured than was indicated by the computor program results. The percentage difference was not as great as the expanded scale of Fig. 34 would indicate.

Test data for two tests which were conducted at low inlet temperatures was also included. The first of these test, Test III, was conducted at an inlet temperature of 715.5 ^{o}R. The low temperature resulted in a temperature drop through the turbine of only 150 ^{o}R. Small errors in measurement of total temperature under such conditions can result in large percentage errors. The test was made at 14,000 rpm or a refered rpm of 523.4. Computor run #14 was made at this refered rpm using areas ratioed down from the measured values to values corresponding to a rotor tip clearance of .015. A curve of refered flow rate versus pressure ratio was drawn, Fig. 34. Run #15 was made using the refered rpm of 594.3 at which Test IV was conducted. The results of the computor run was plotted, Fig. 34. In both cases the flow rate obtained by the actual tests was slightly greater than the theoretical value calculated by the computor. The efficiency calculated from the actual tests was much greater however, 84% compared to 77% for the theoretical computations.

During the final reading of this paper it was discovered that the sign of the incidence angles of the flow into Rotor I and Rotor II was not in accordance with the sign convention adopted, Fig. 2. As a result the loss coefficients presented in Tables IV and VI, and the corresponding graphs, Fig. 18 and 20, are in error. The error involved will not cause a significant change in the loss coefficients or performance of the turbine under normal operating conditions. At reduced flow rates, where the incidence angle of the flow entering a rotor blade row is considerably larger than the blade angle, the loss coefficients will be less than those presented in Table V and VII.

Vavra continued the investigation of the performance of this turbine using the same basic method. Loss coefficients for the rotors were calculated with the sign of the incidence angles of the flow into the rotors taken in accordance with the sign convention presented in Fig 2. Since the Reynolds number of the flow corresponding to design conditions is approximately 7 x 10^5, and is considerably greater than 2 x 10^5 for which the data in Ref. 6 applies, the profile loss coefficients were corrected for Reynolds number effects using the empirical relation suggested in Ref. 6

$$\zeta_P = (2/7)^{.2} \times \left[\zeta'_P \text{ (for } R_e = 2 \times 10^5)\right]$$

The values of ζ'_P were reduced by 22.2%.

Vavra developed a computor program independently and made a run using the same assumed rotor tip clearances, flow areas, and refered speed as Run 2. The results of this run are presented in Table VIII. A maximum turine efficiency of 80.6% was obtained for a pressure ratio of 2.56 and a refered flow rate of 3.80 Considering the reduction in profile loss coefficients, the efficiency compares favorably with the value of 78.4%, for a pressure ratio of 2.69 and a refered flow rate of 3.72, obtained from Run 2.

XI. Conclusions

This method of turbine performance analysis will provide an accurate and rapid means of determining the performance of a subsonic, axial flow, multistage turbine providing the actual measured flow areas and rotor tip clearances existing during operation at high temperatures are known. A reduction in clearance will cause a corresponding reduction in flow area and flow rate for a given pressure ratio, and increase the efficiency.

All the dimensionless parameters needed to completely define turbine performance can be obtained from the turbine performance maps. These maps show the effects of changes of one or more parameters upon the others. The plot of refered flow rate versus pressure ratio shows that a relatively large increase in pressure ratio is required to produce a small increase in refered flow rate at pressure ratios close to critical.

As a result of the analysis of the performance of the two stage turbine investigated it can be concluded that the turbine operates at a maximum efficiency of 78.4% when running at the design refered rpm and a pressure ratio of 2.69. The power coefficient corresponding to these conditions is .189. The operation of the turbine will be restricted to a fairly narrow range of velocity ratio with maximum efficiency occuring at a velocity ratio of .445. The efficiency at this velocity ratio varies very little until pressure ratios too low to be used in normal operation are reached.

The redesign of the nozzle blade row, as proposed by the manufacturer, would reduce the pressure losses and increase the efficiency approximately 3% to a maximum efficiency of 81.9%.

Correlation between the test data and program results was as good as could be expected considering the limited amount of test data available. In all cases the measured flow rates for a given pressure ratio were greater than the theoretical values determined by the computor programs, however the percentage differances were not excessive and closer correlation should be possible with additional computor runs

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8. Vavra, M.H., (unpublished paper).

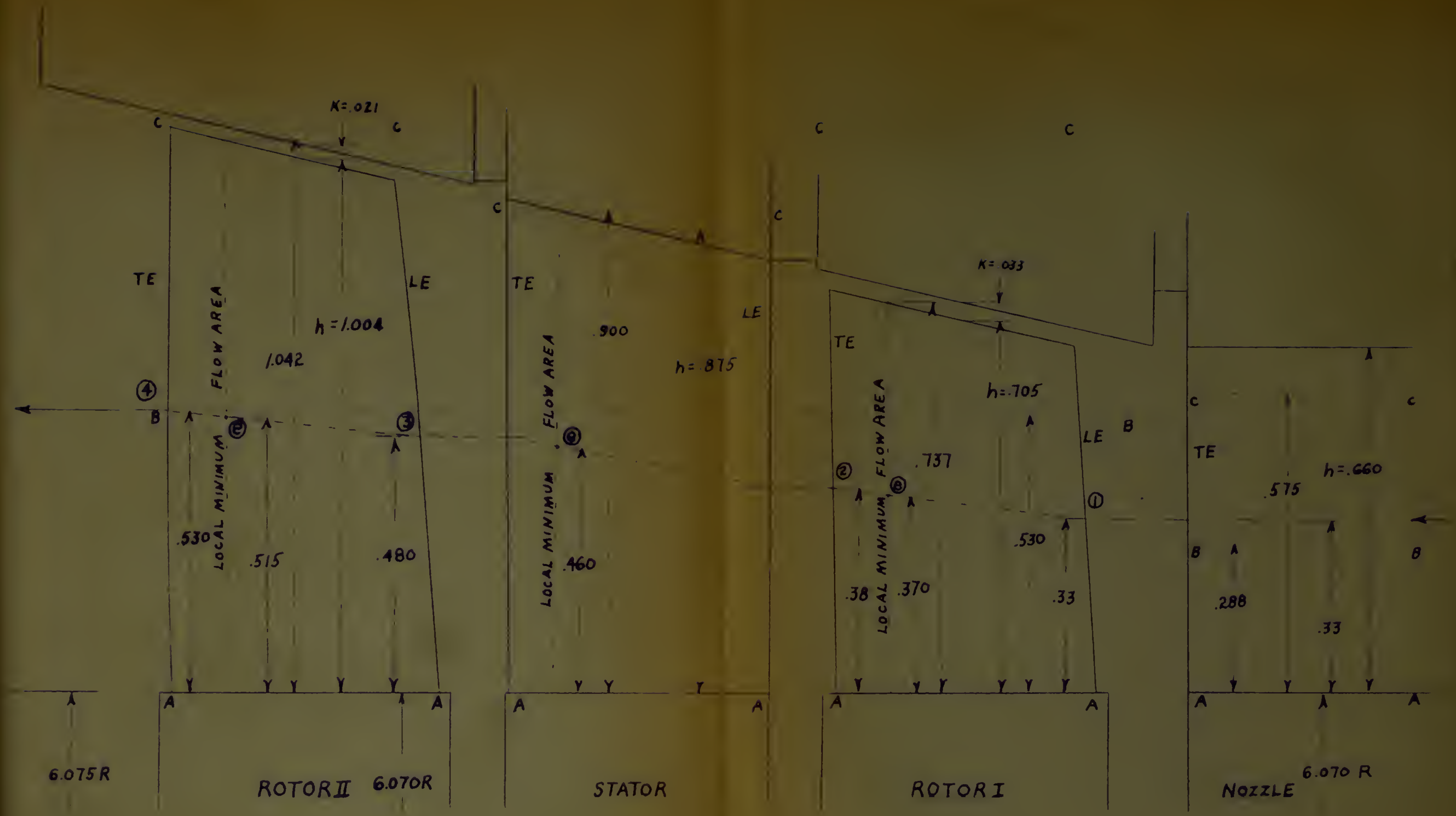


FIG. 1
MERIDIONAL BLADE PASSAGE
SCALE 5:1

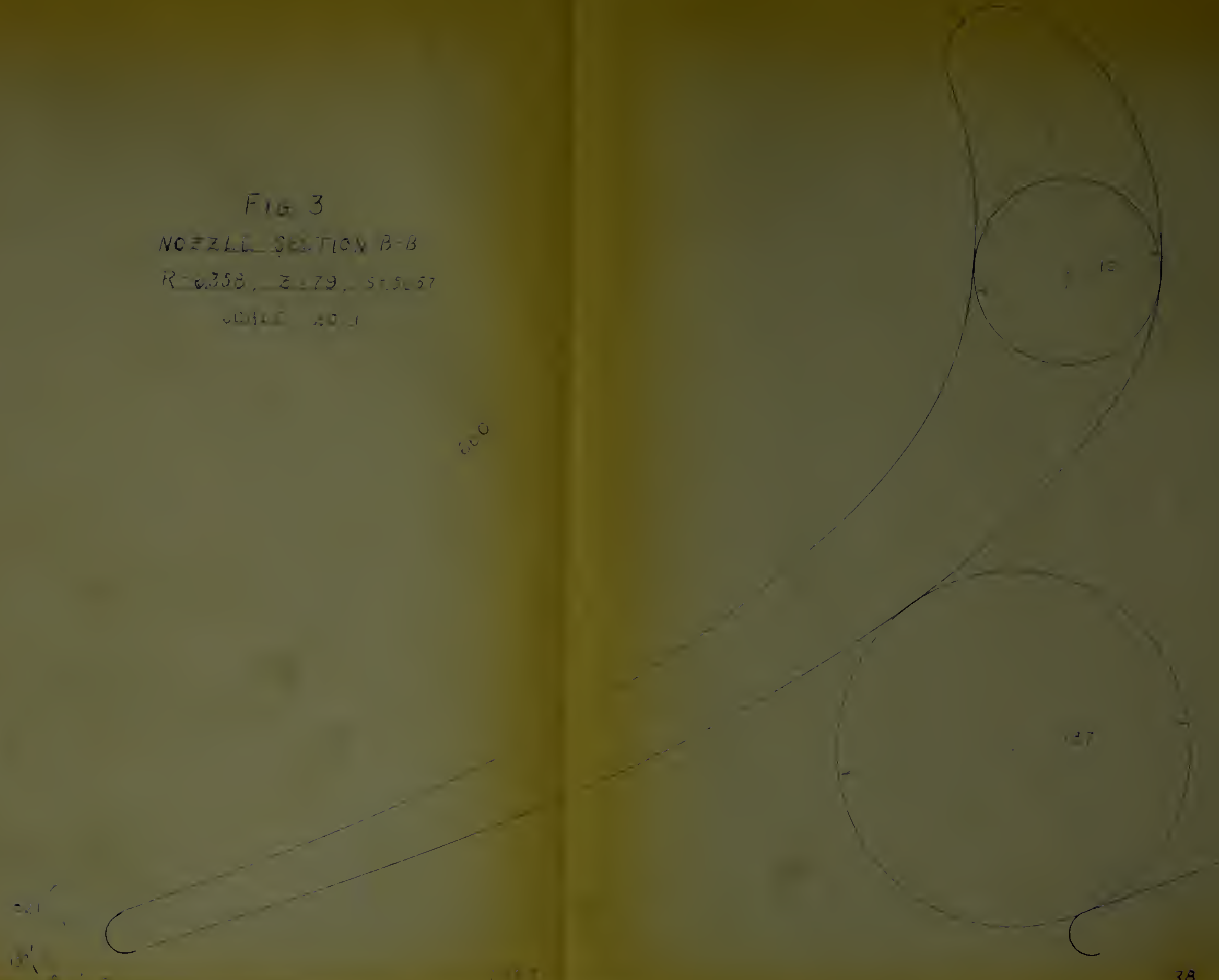


FIG 3

NOZZLE SECTION B-B

R = 6.358, Z = 79, S = 5.57

SCALE 20:1

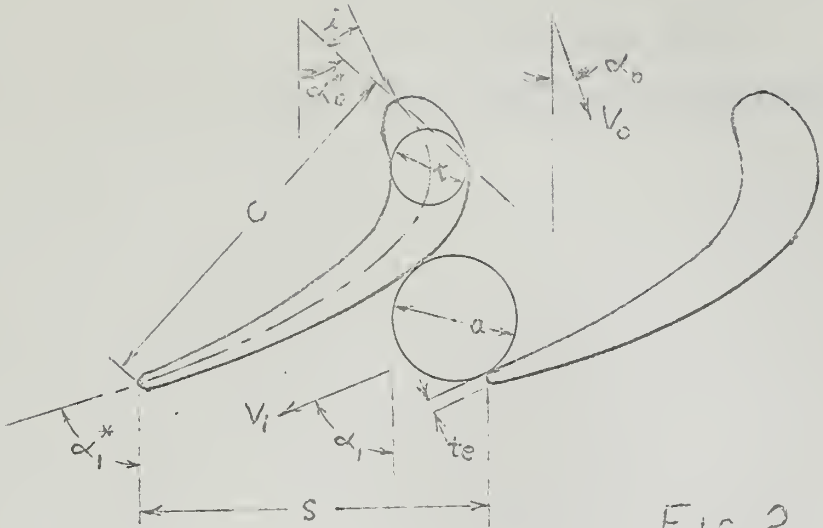


FIG. 2

Blade Row and Gas Angle Geometry

c chord -- straight line connecting the ends of the camber line

t maximum thickness of blade

s spacing -- blade pitch

a blade opening or throat -- height of minimum flow area

t_e trailing edge thickness

α_0 inflow angle

α_1 discharge angle

α_0^* blade angle at inlet

α_1^* blade angle at trailing edge

i incidence angle

α designates stator blade angles

β designates rotor blade angles

Sign Convention: (1) Angles are positive where velocity vectors have components in the direction of rotor motion.

(2) Incidence angles are positive when the deflection angle is greater than for a flow entering at the blade angle.

(3) Gas axial velocity is always positive.

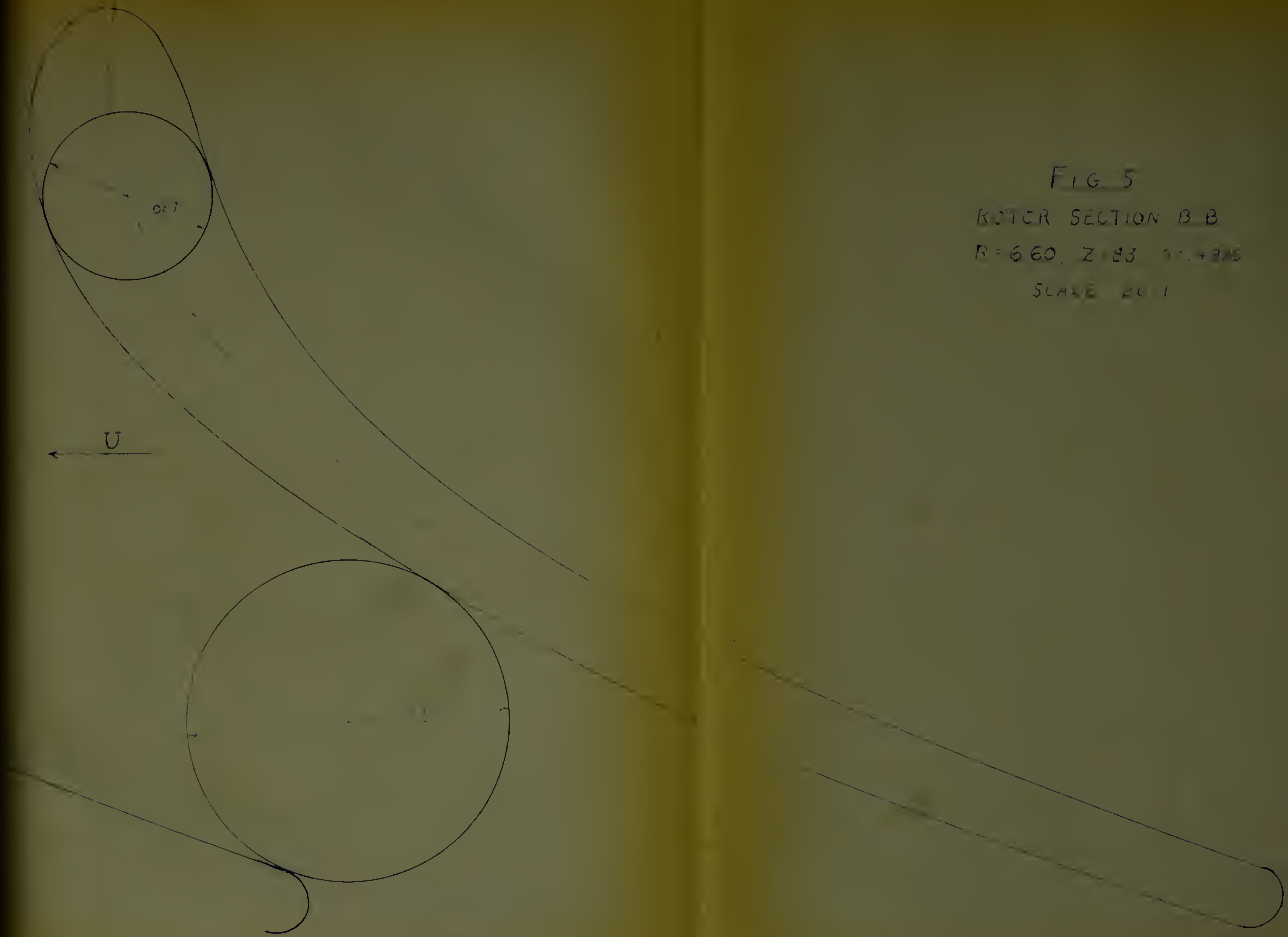


FIG. 5

ROTOR SECTION B-B

R = 6.60, Z = 83 [illegible]

SCALE 20:1

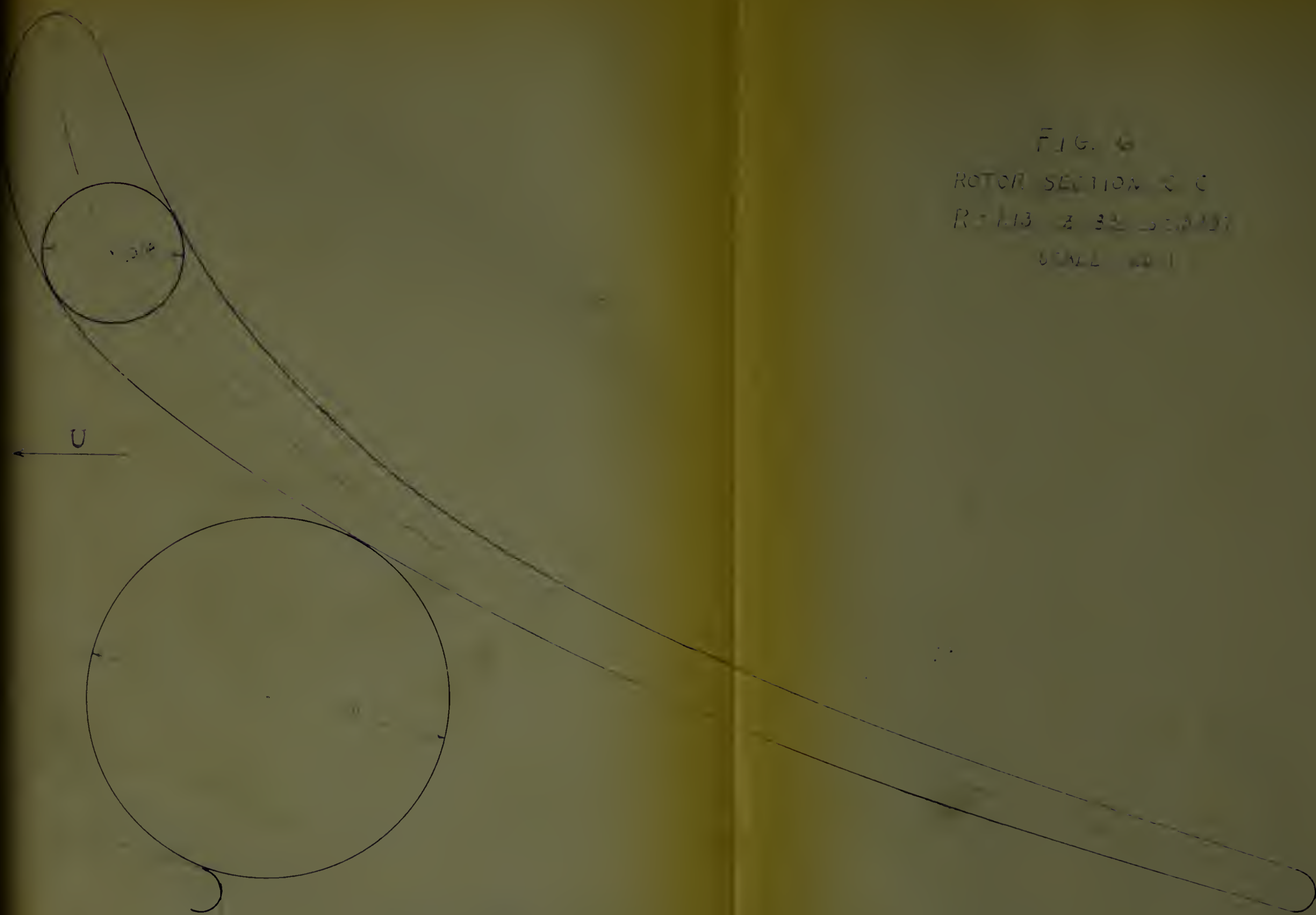


FIG. 6

ROTOR SECTION C-C

R = 1.13 [illegible]

SCALE [illegible]

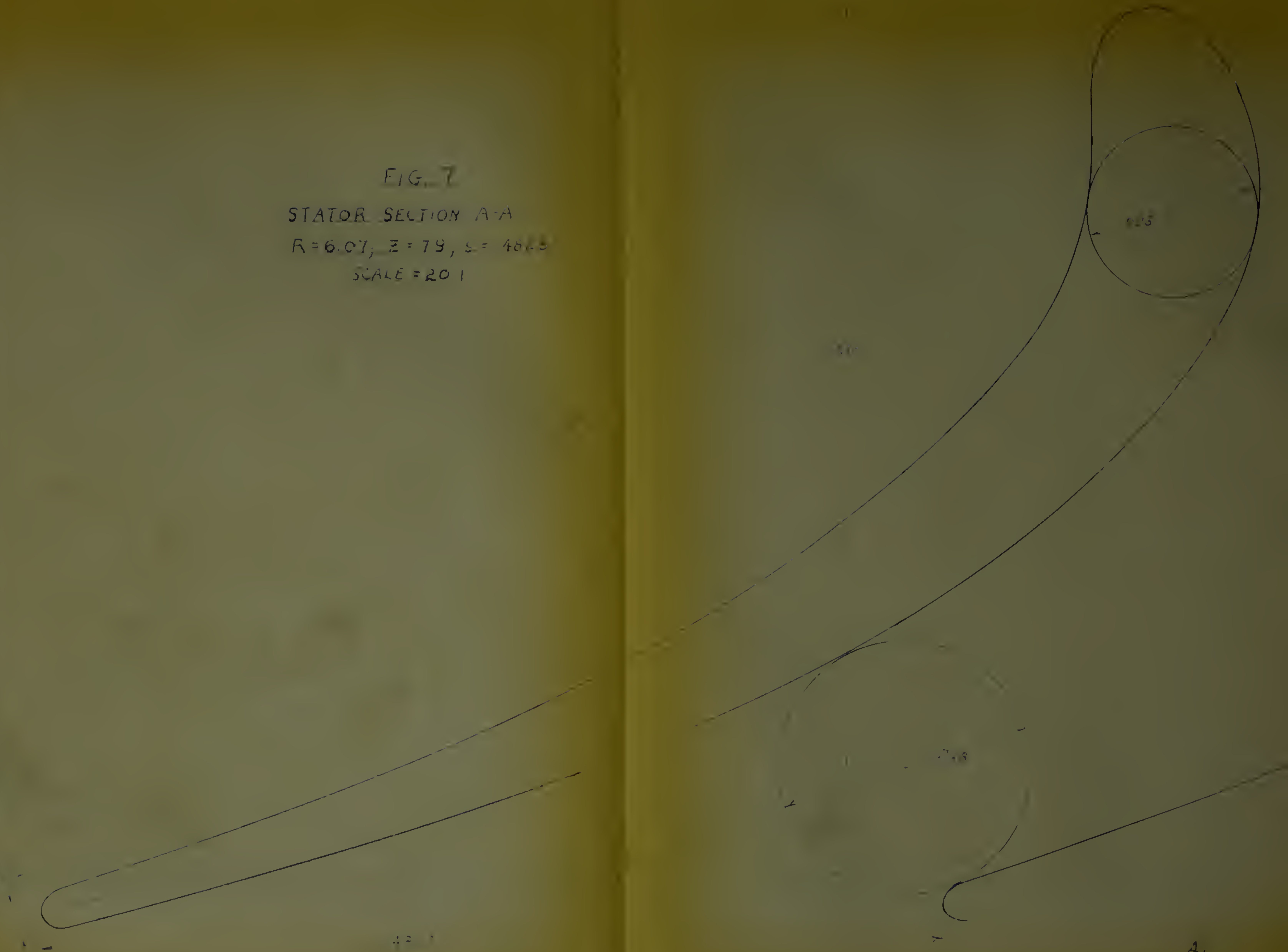


FIG. 7

STATOR SECTION A-A

R = 6.07; Z = 79, S = 48[illegible]

SCALE = 20 1

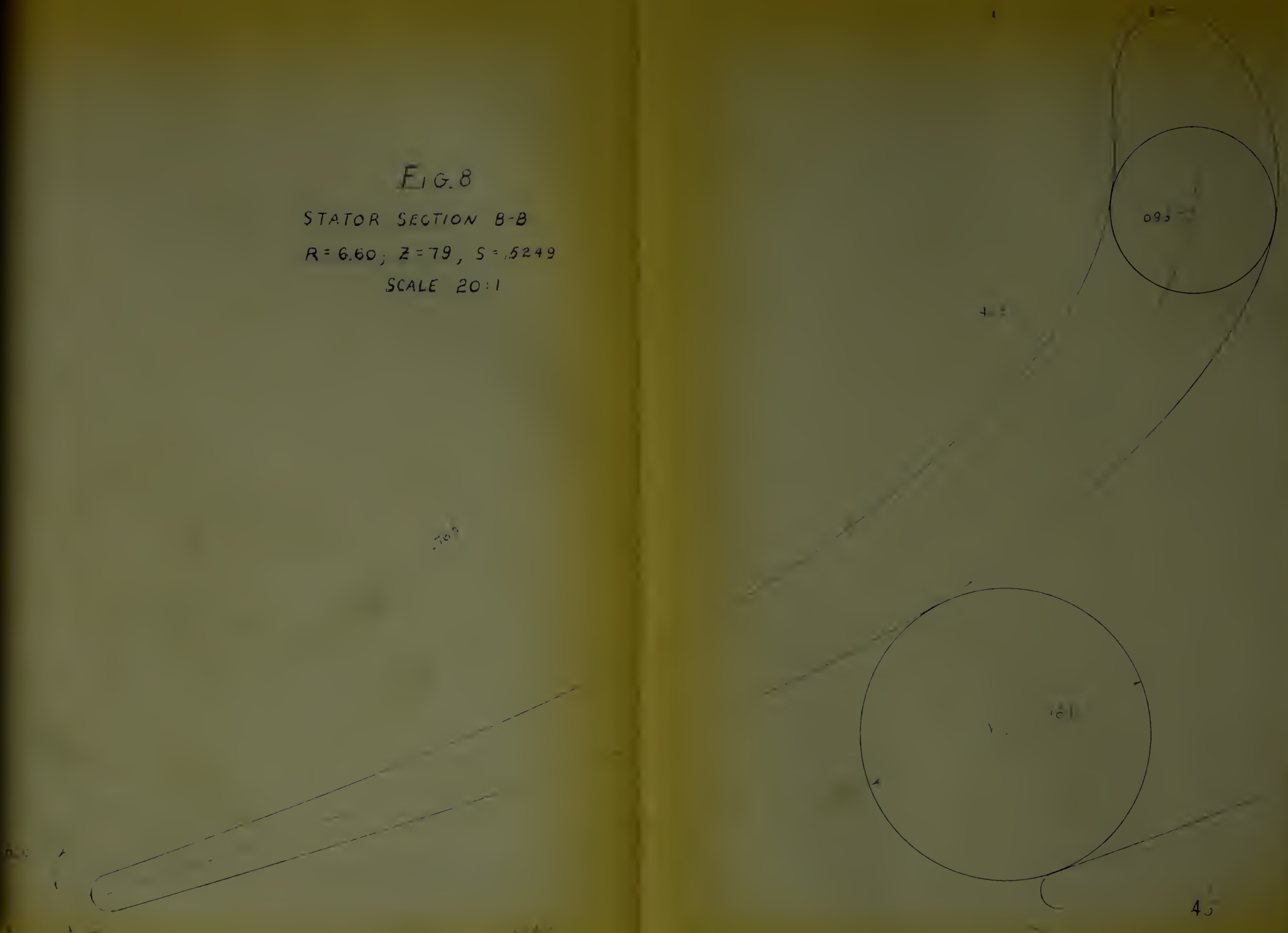


FIG. 8

STATOR SECTION B-B

R = 6.60; Z = 79, S = .5249

SCALE 20:1

FIG. 9

STATOR SECTION C-C

R = 6.98 ; Z = 79 , S = .5552

SCALE 20:1

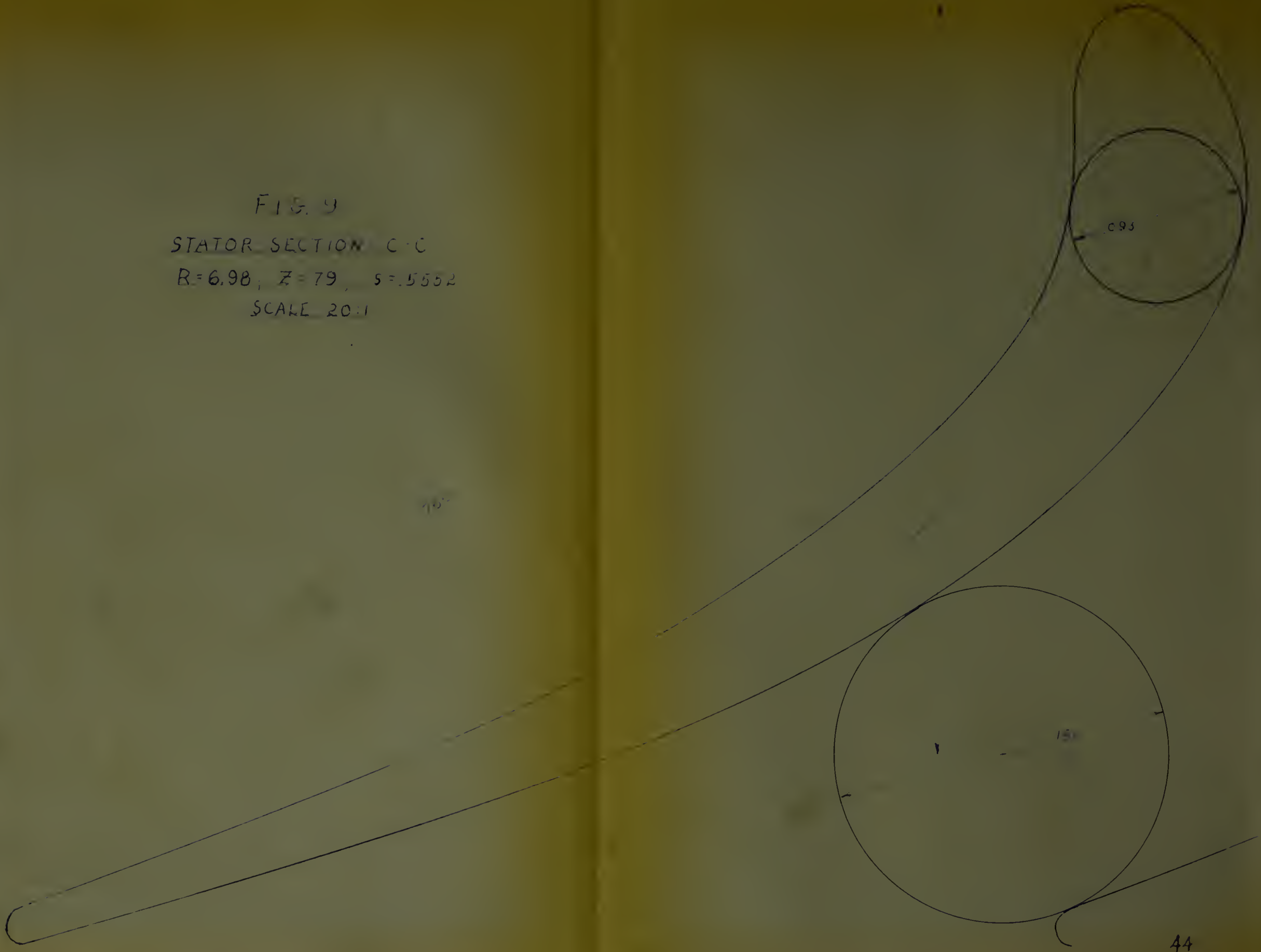
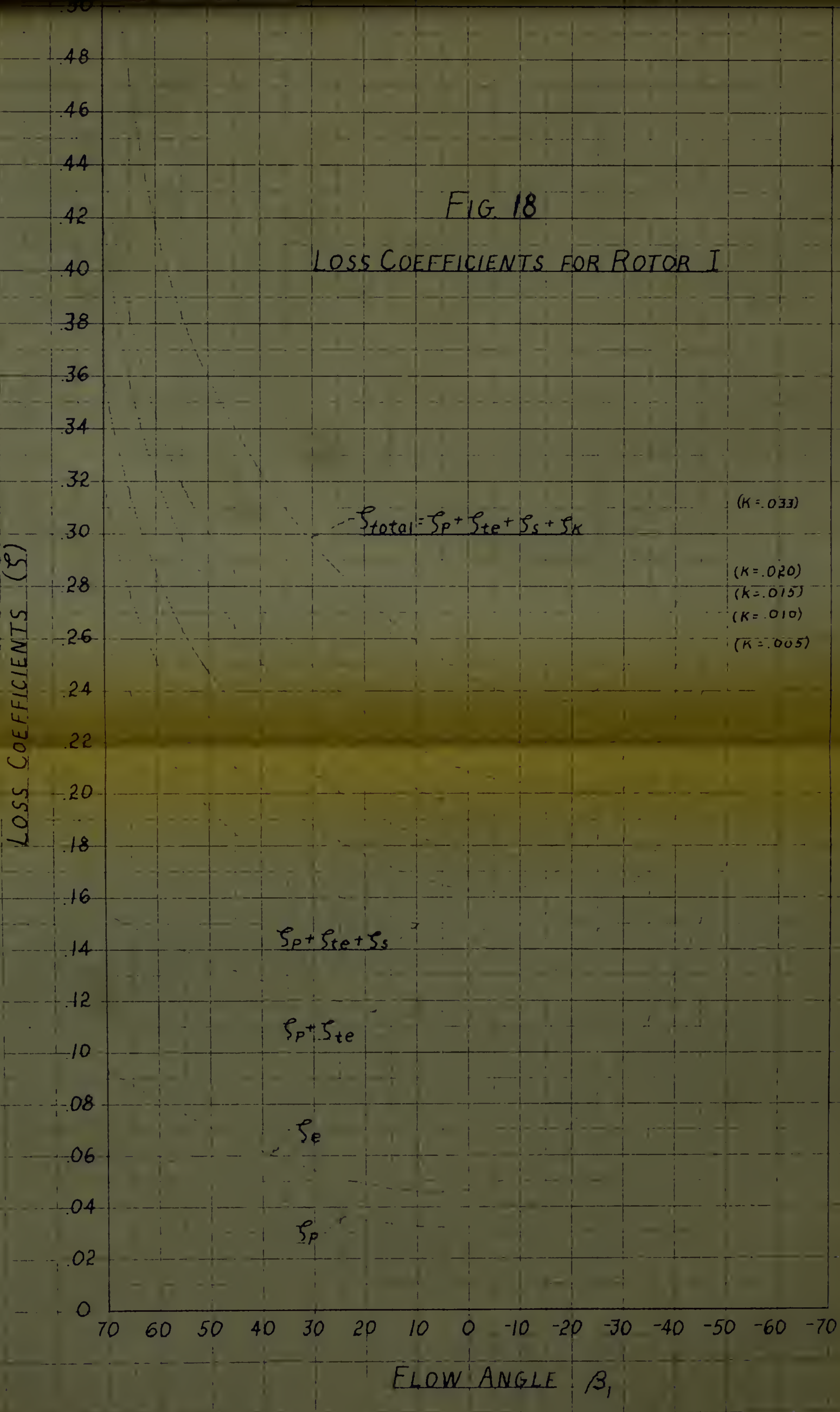


Fig. 18

Loss Coefficients for Rotor I



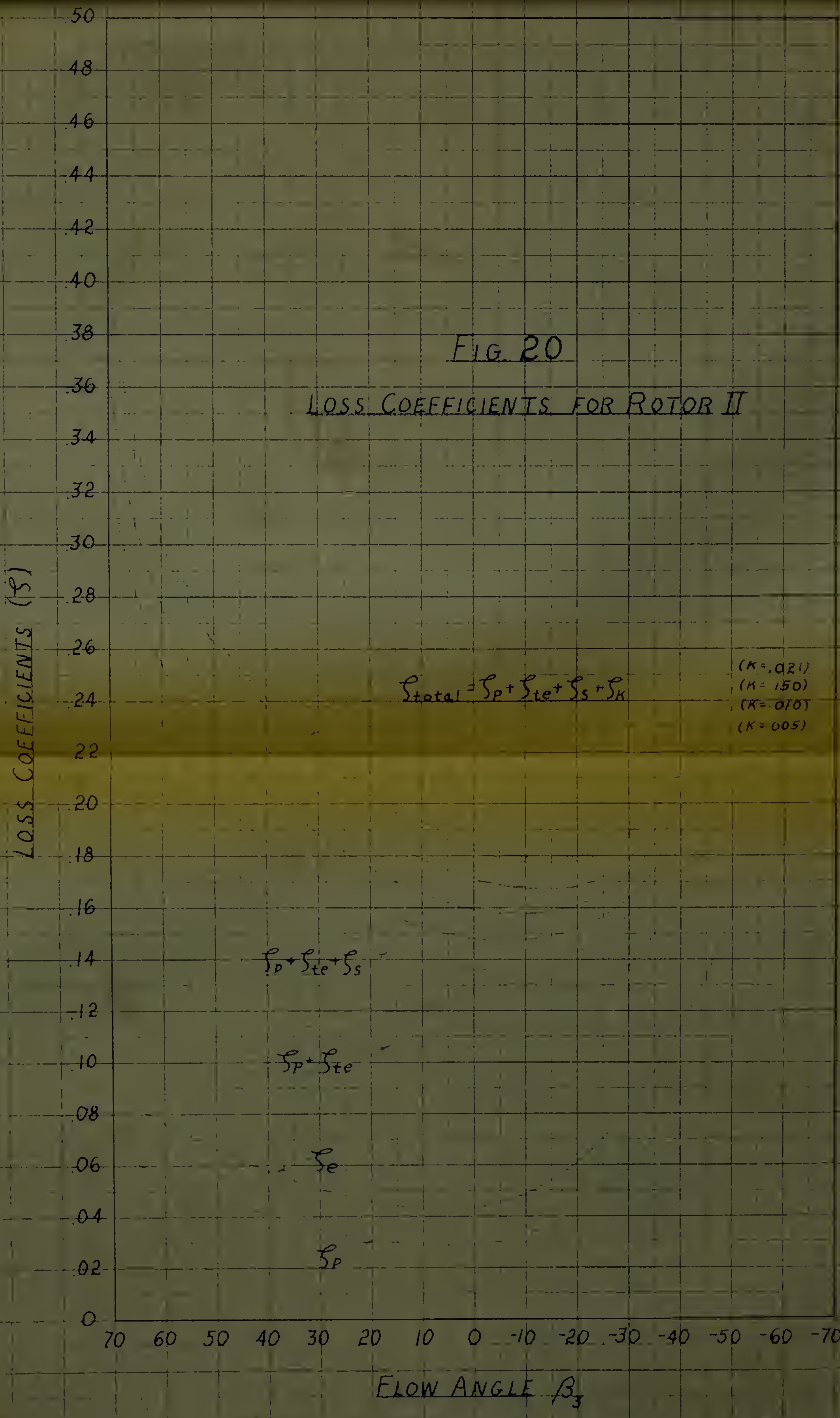
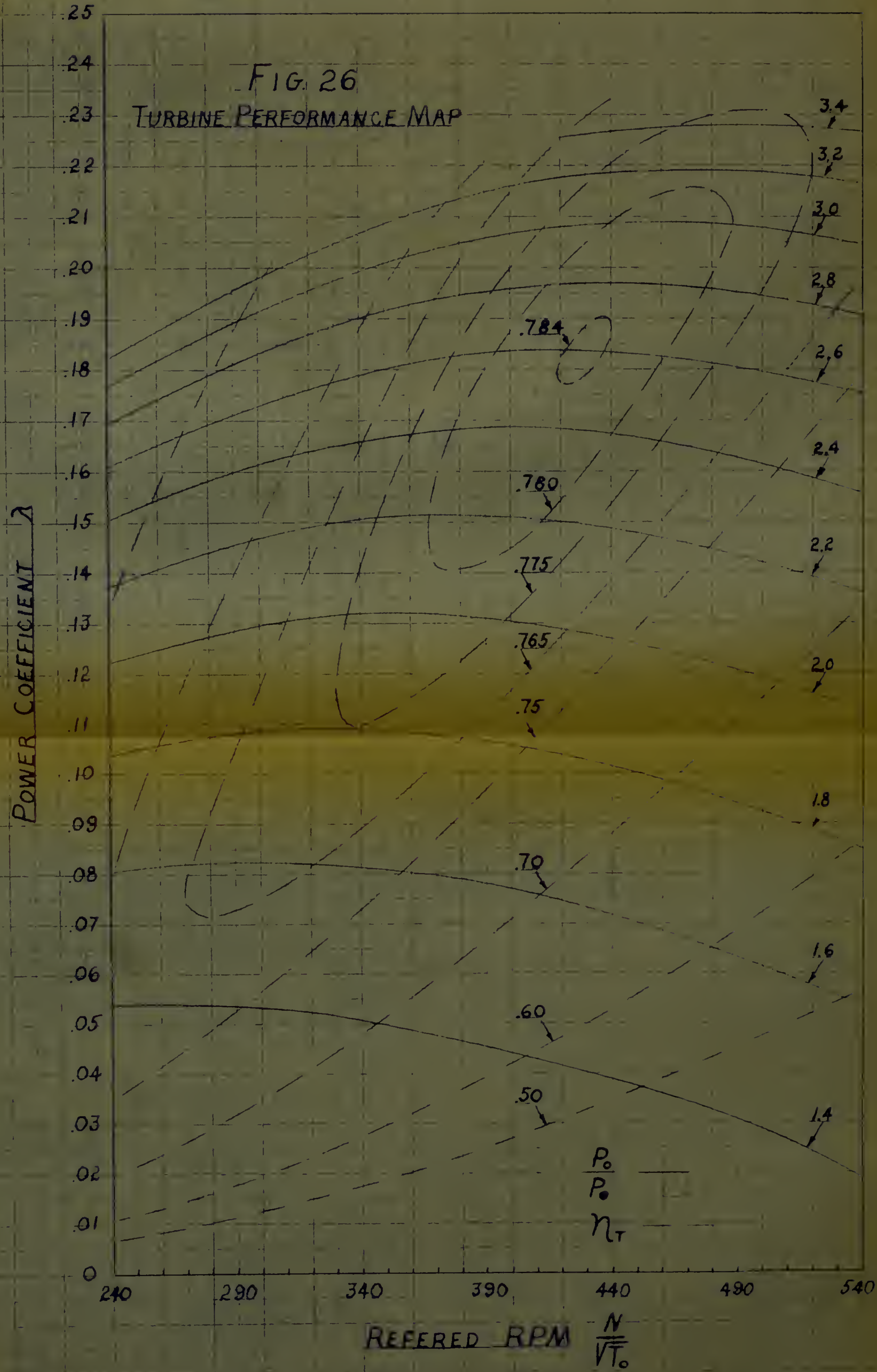


FIG. 20

LOSS COEFFICIENTS FOR ROTOR II

Fig. 26

Turbine Performance Map



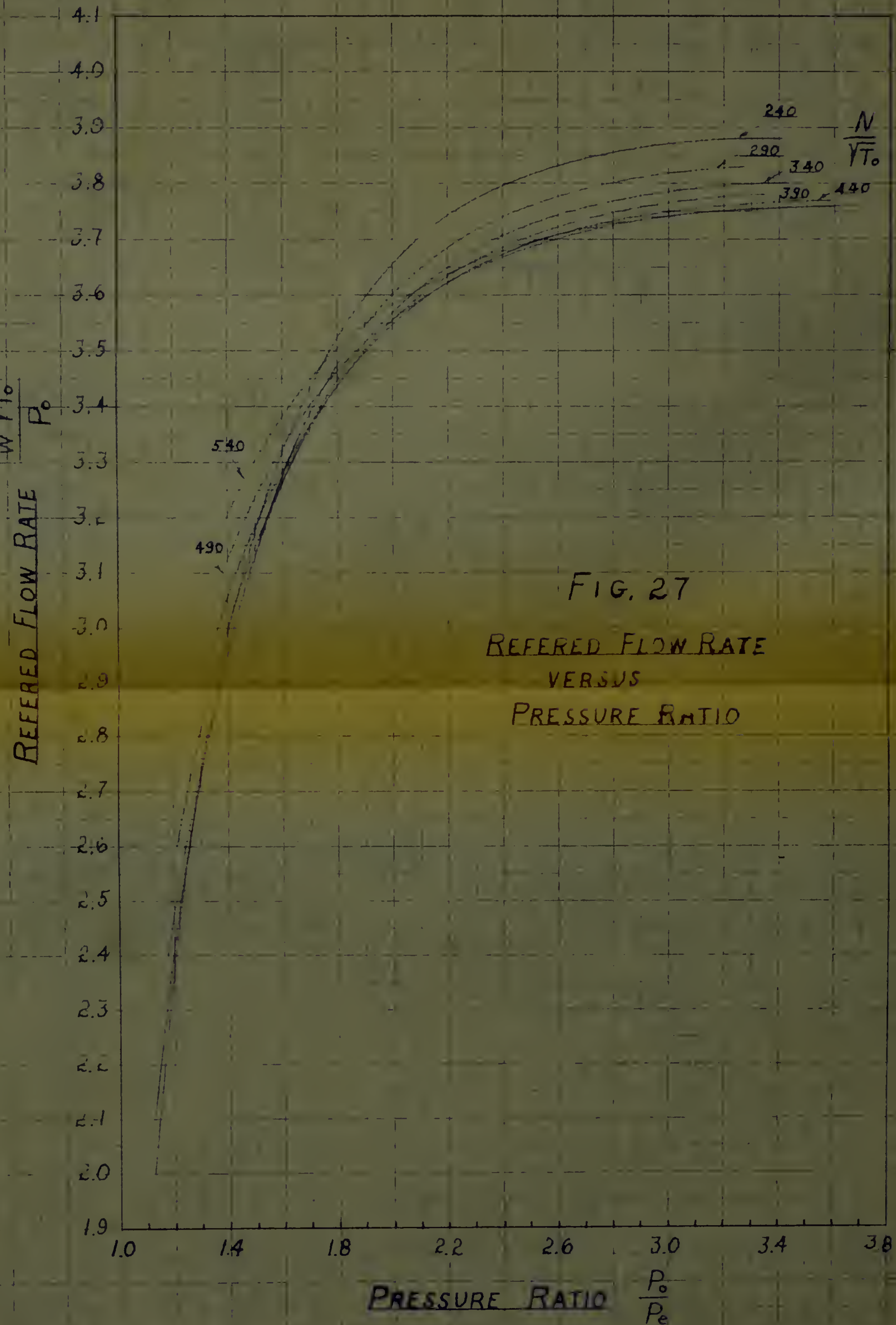


FIG. 27

REFERED FLOW RATE
VERSUS
PRESSURE RATIO

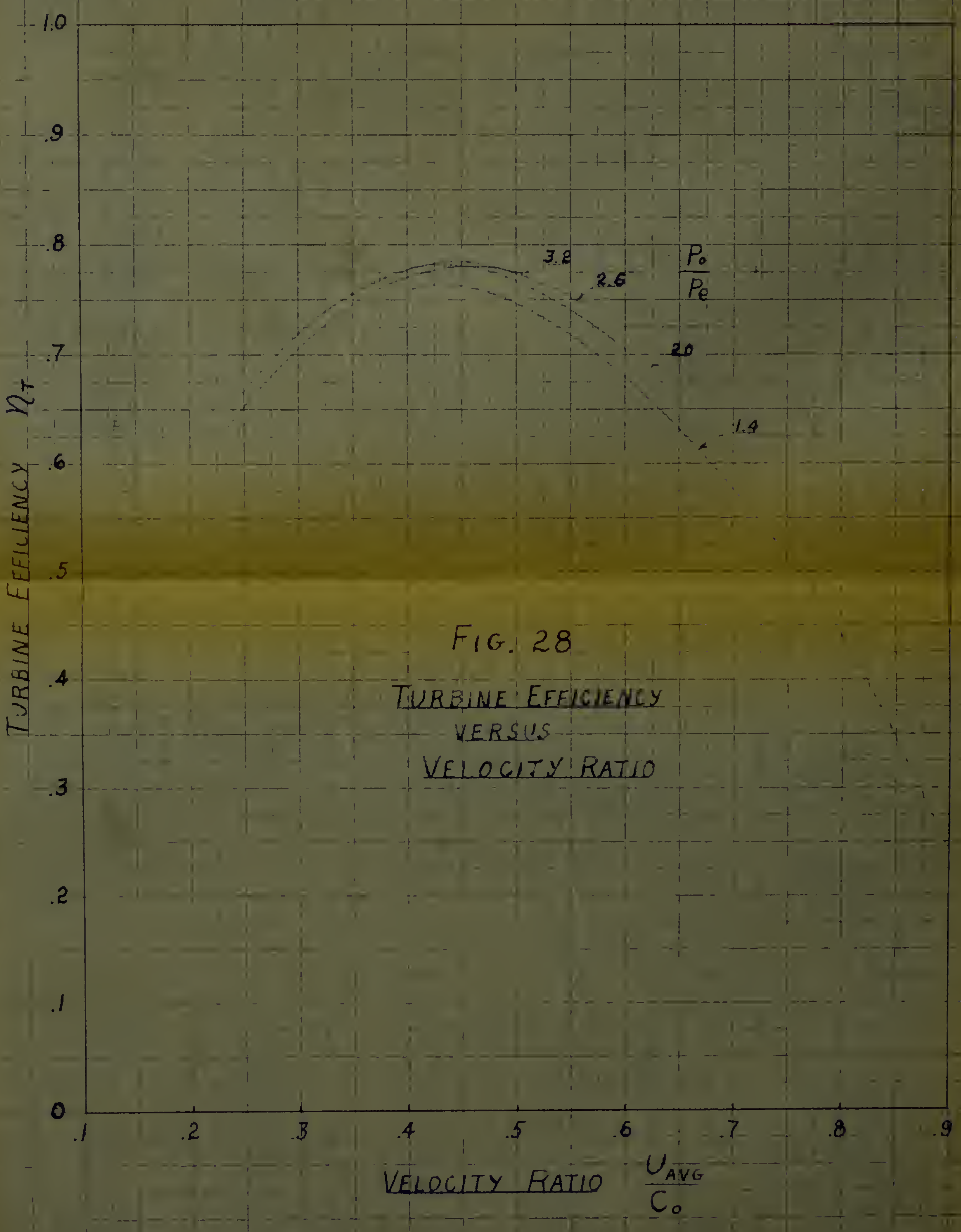


Fig. 28

Turbine Efficiency

versus

Velocity Ratio

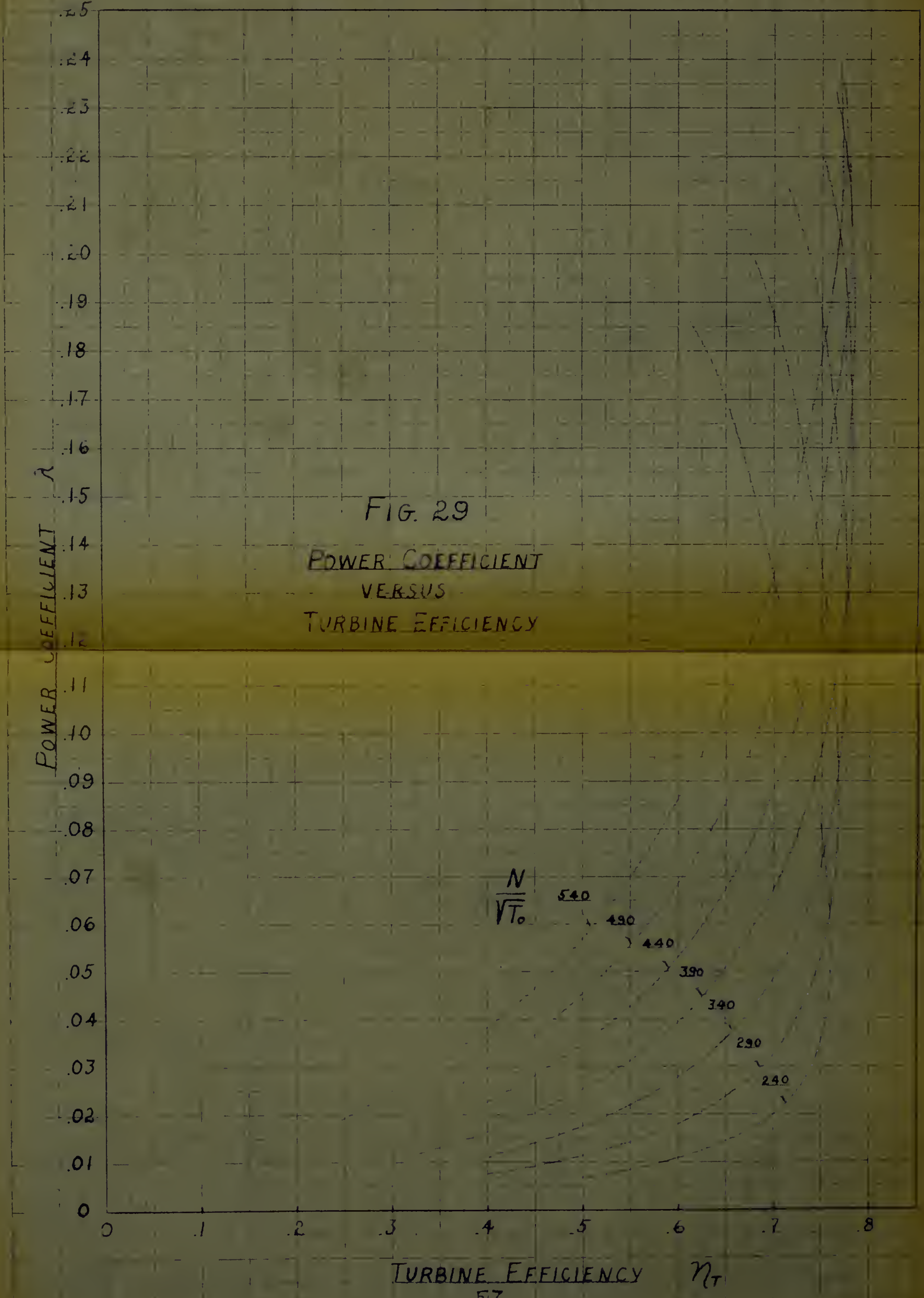


FIG. 29
POWER COEFFICIENT
VERSUS
TURBINE EFFICIENCY

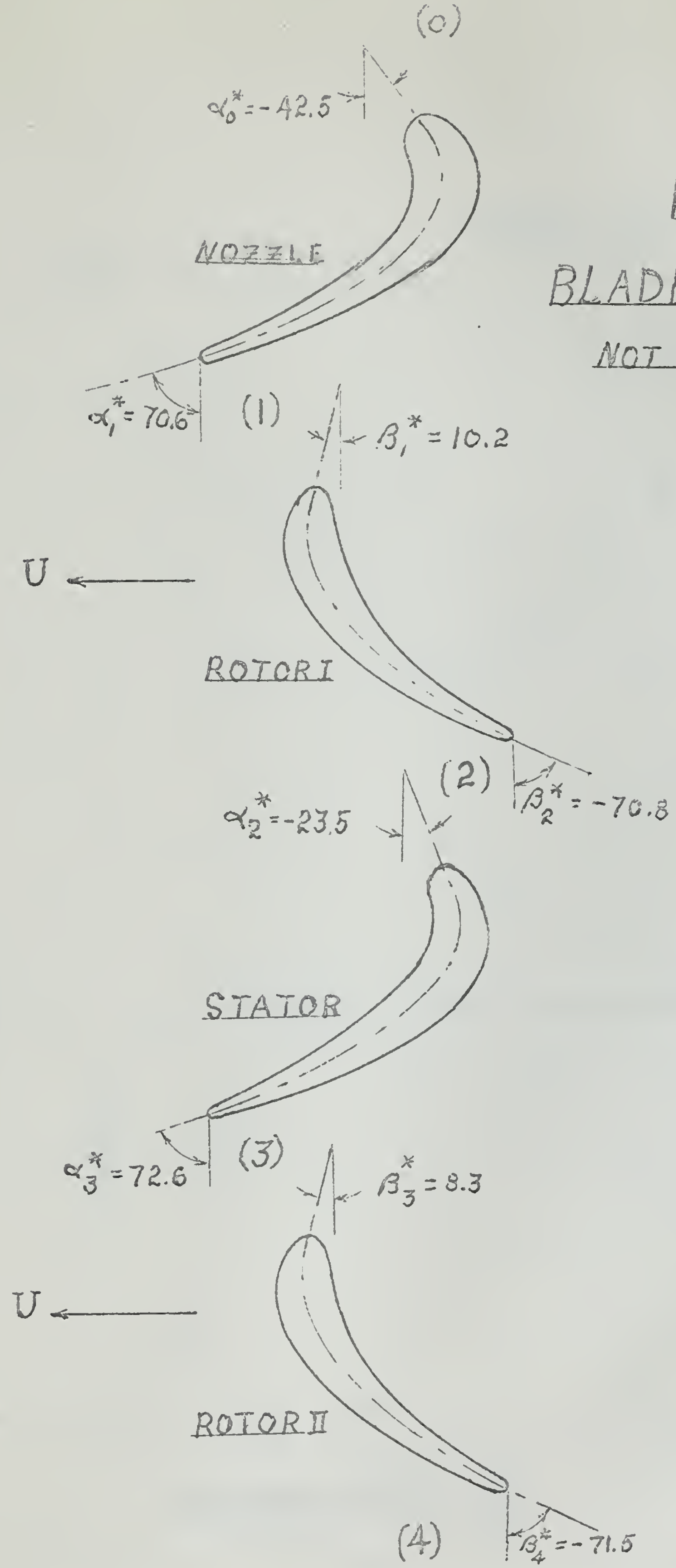


FIG. 10
BLADE ANGLES
NOT TO SCALE

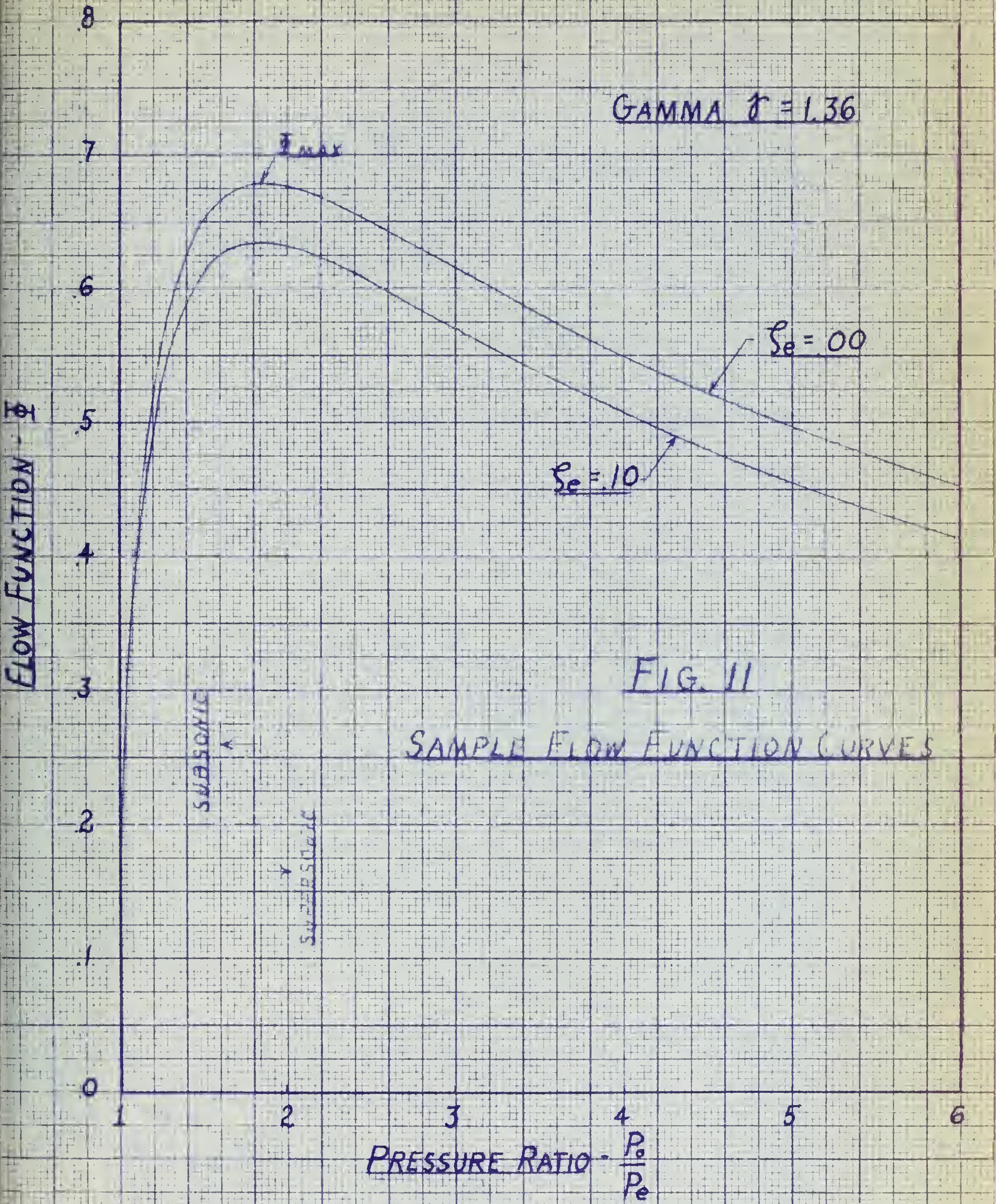


FIG. 11

SAMPLE FLOW FUNCTION CURVES

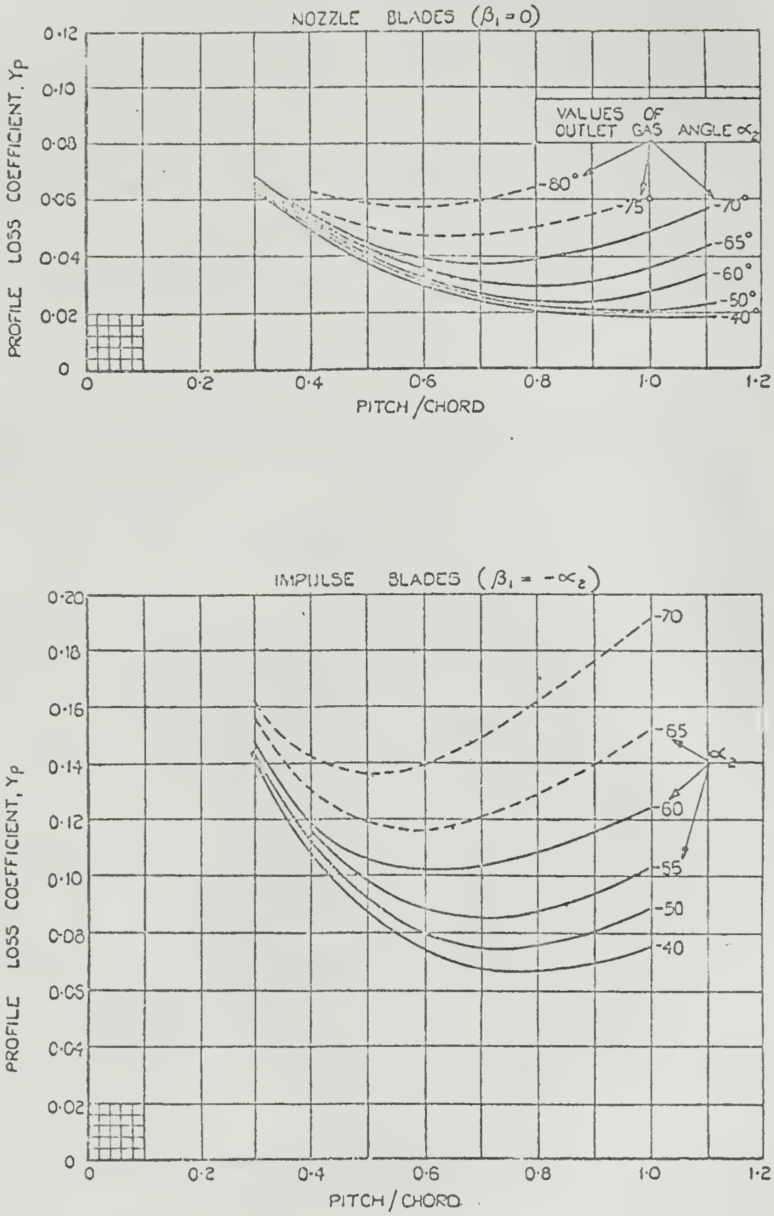


FIG. 13. Profile-loss coefficients for conventional section blades at zero incidence. ($t/c = 20$ per cent ; $R_e = 2 \times 10^5$; $M < 0 \cdot 6$.)

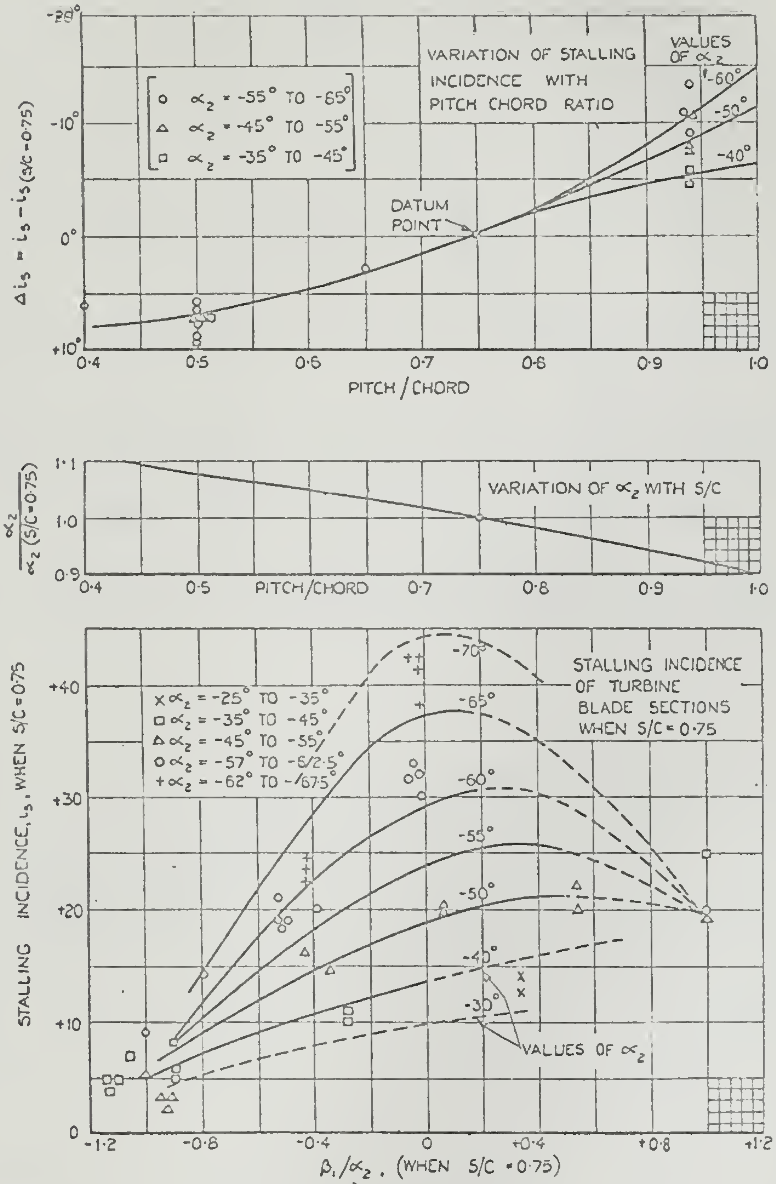


Fig. 14. Positive stalling incidences of cascades of turbine blades.
$Re = 2 \times 10^5$; $M < 0{\cdot}6$.

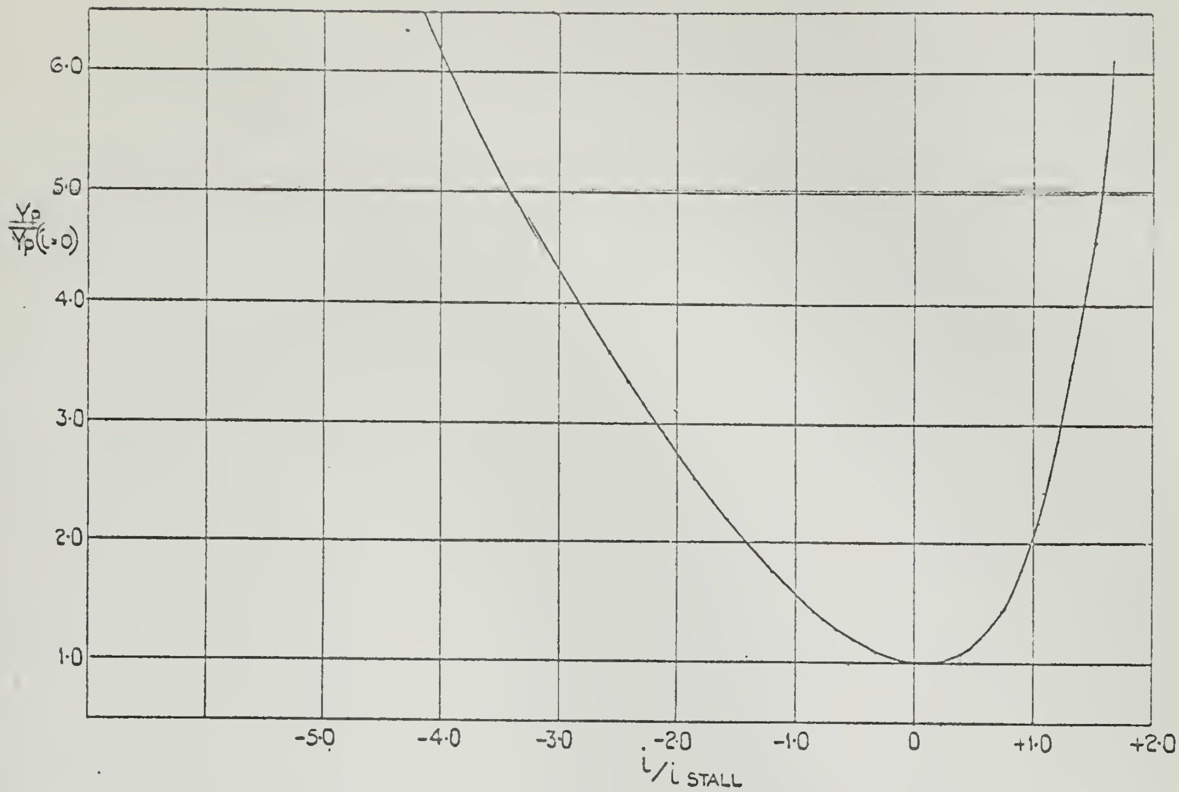


FIG. 15. Variation of profile loss with incidence for typical turbine blading.

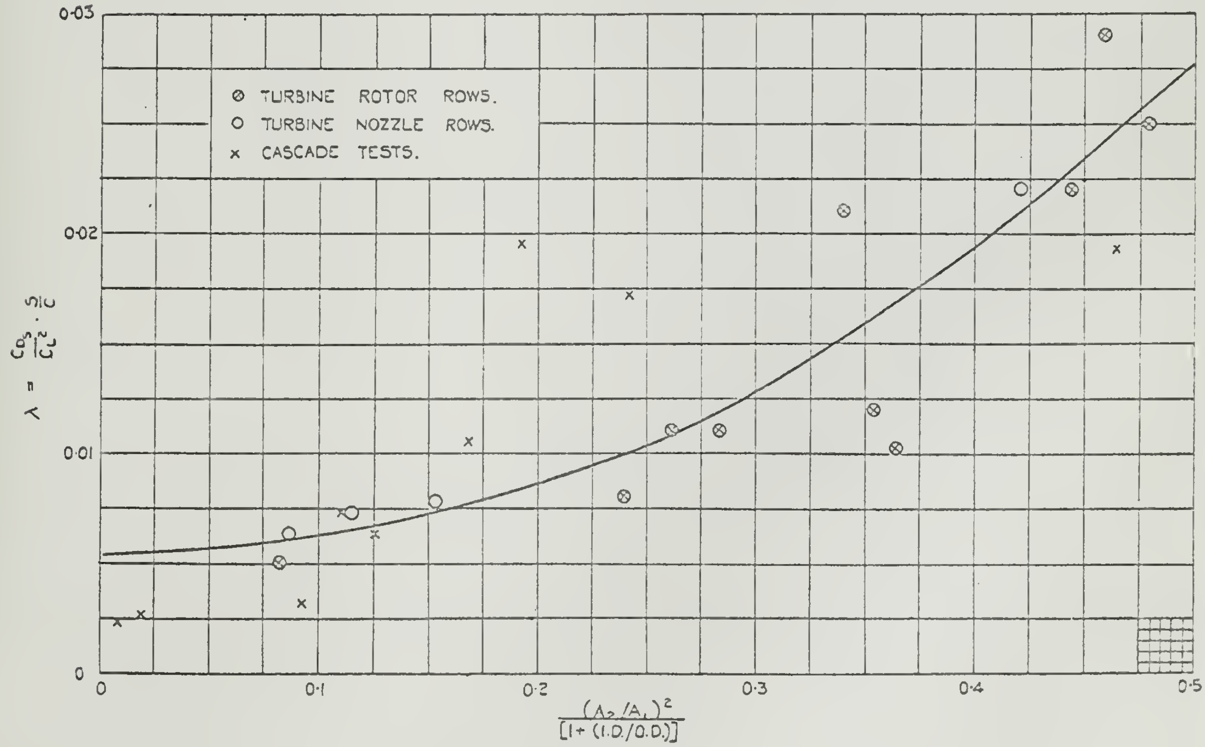


FIG. 16. Secondary losses in turbine blade rows.

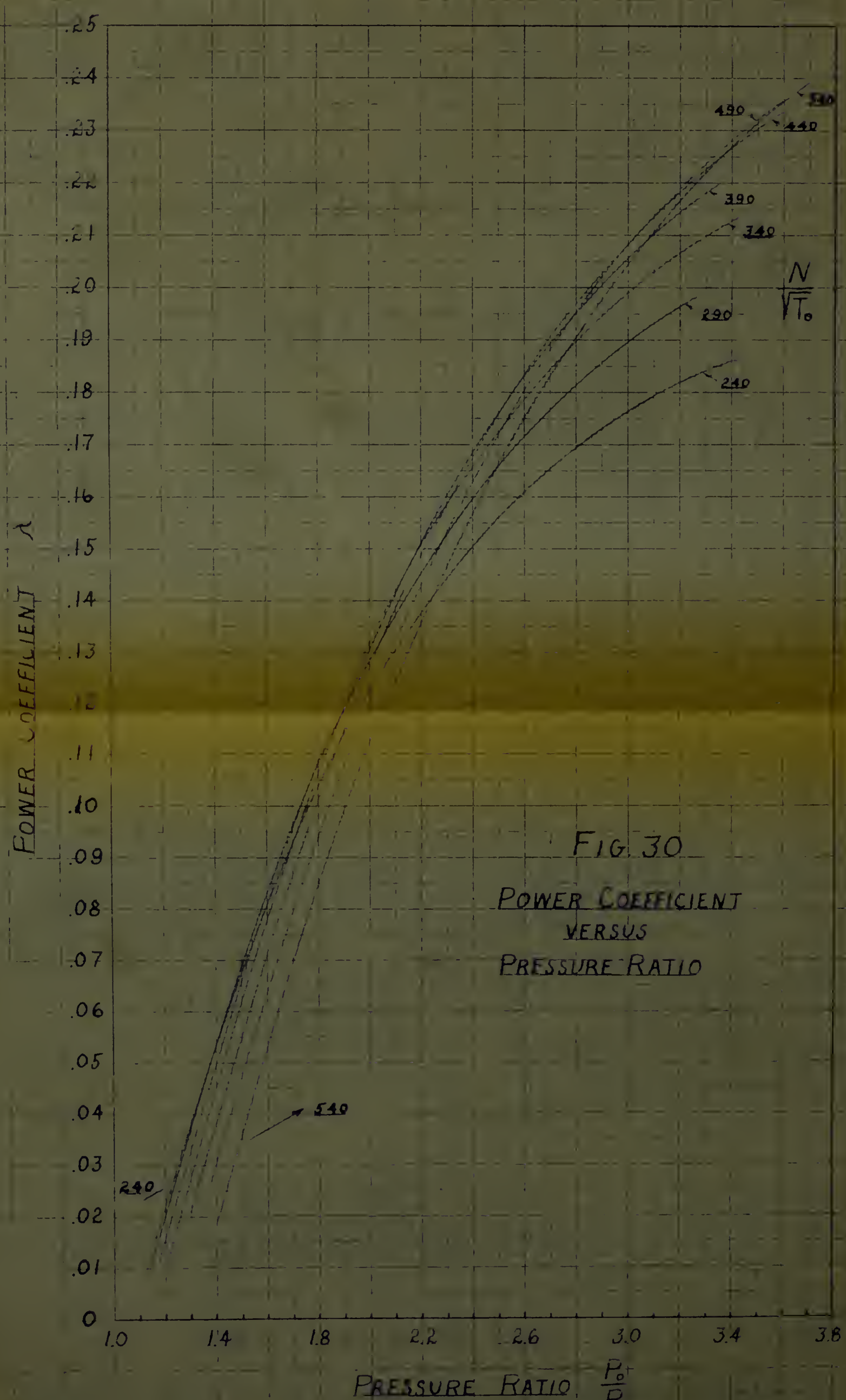


FIG. 30

POWER COEFFICIENT
VERSUS
PRESSURE RATIO

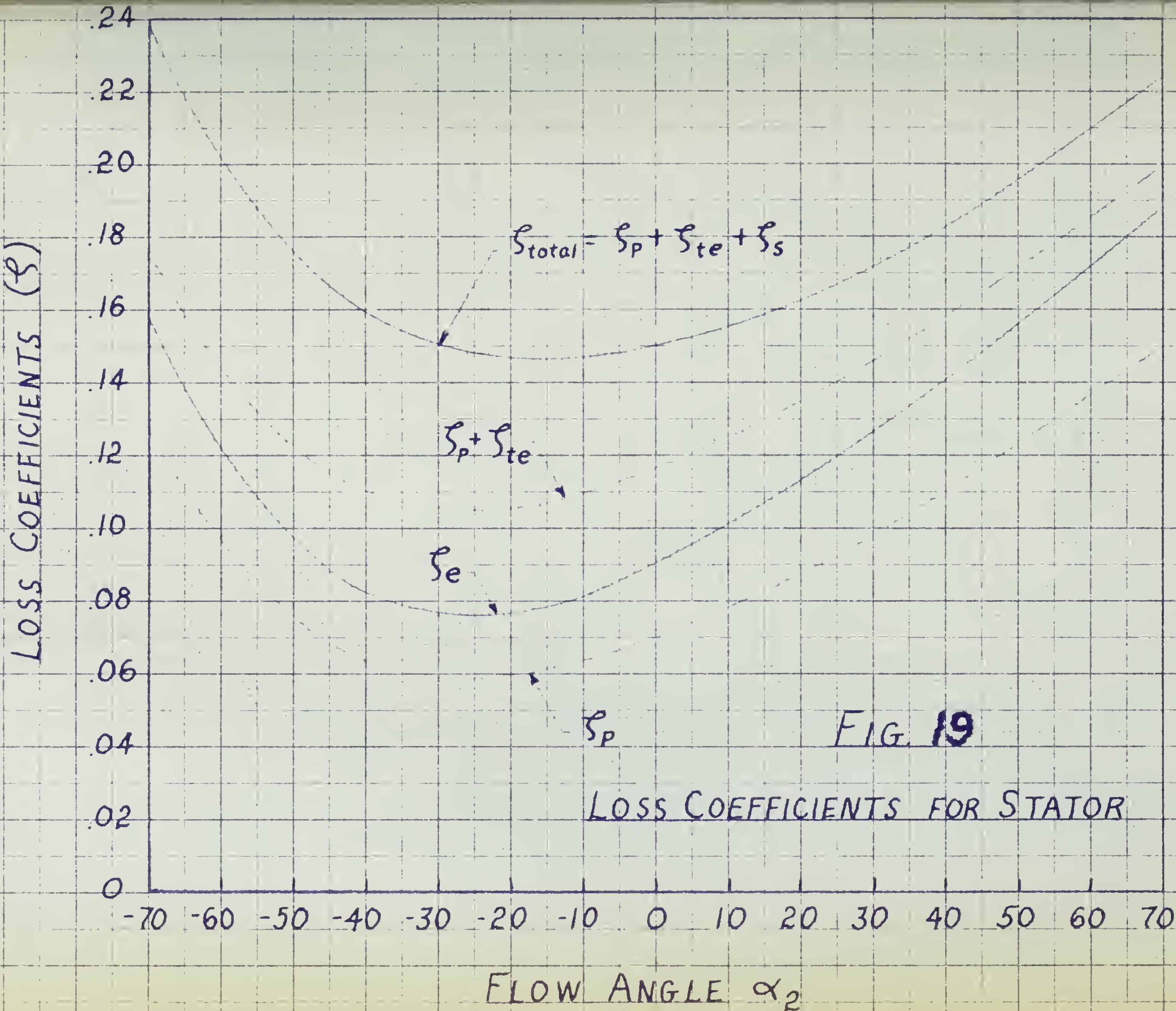


FIG. 19

LOSS COEFFICIENTS FOR STATOR

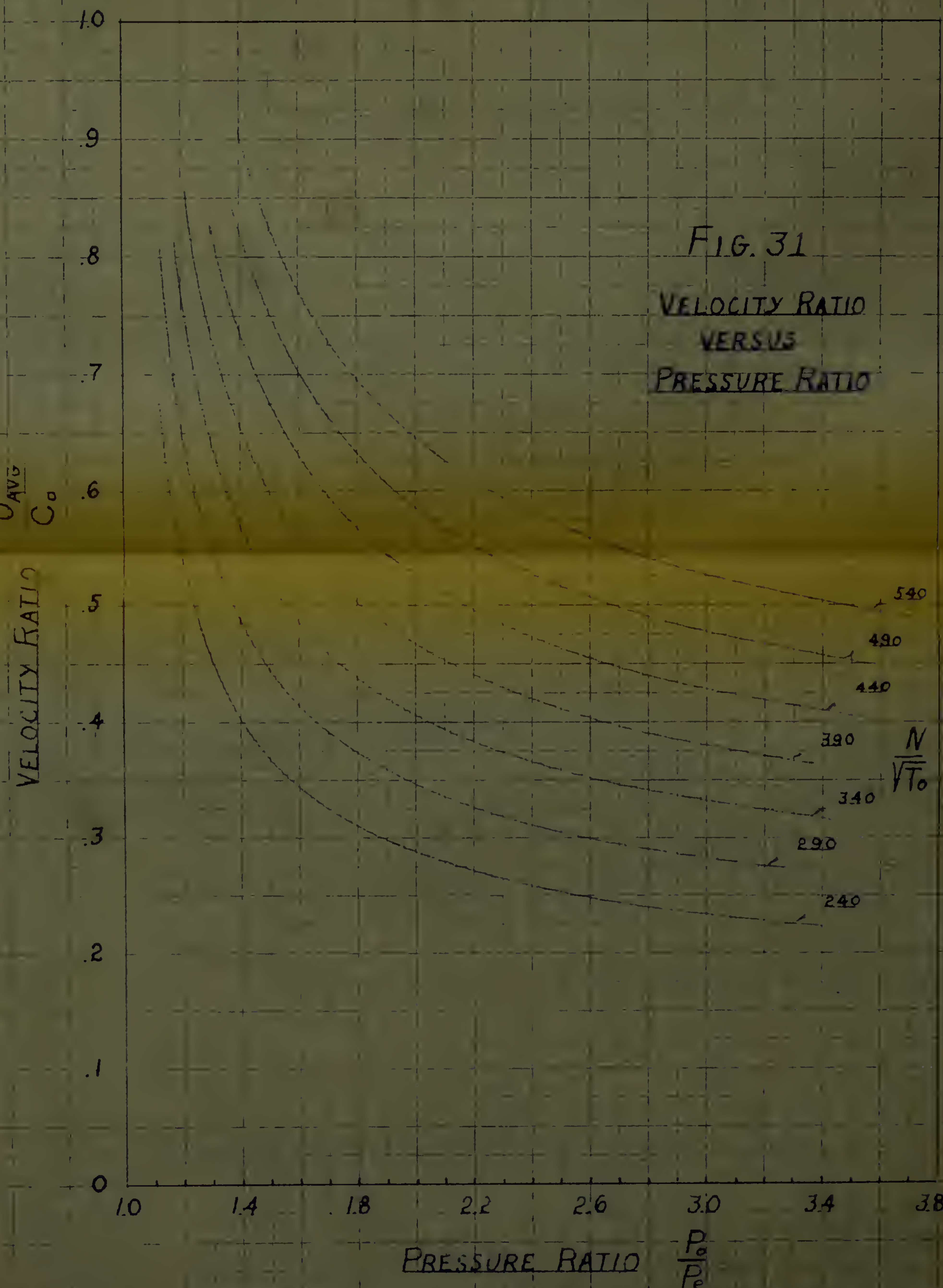


FIG. 31
VELOCITY RATIO
VERSUS
PRESSURE RATIO
VELOCITY RATIO $\frac{U_{AVG}}{C_o}$
PRESSURE RATIO $\frac{P_o}{P_e}$
$\frac{N}{\sqrt{T_o}}$
540
490
440
390
340
290
240
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.4
1.8
2.2
2.6
3.0
3.4
3.8

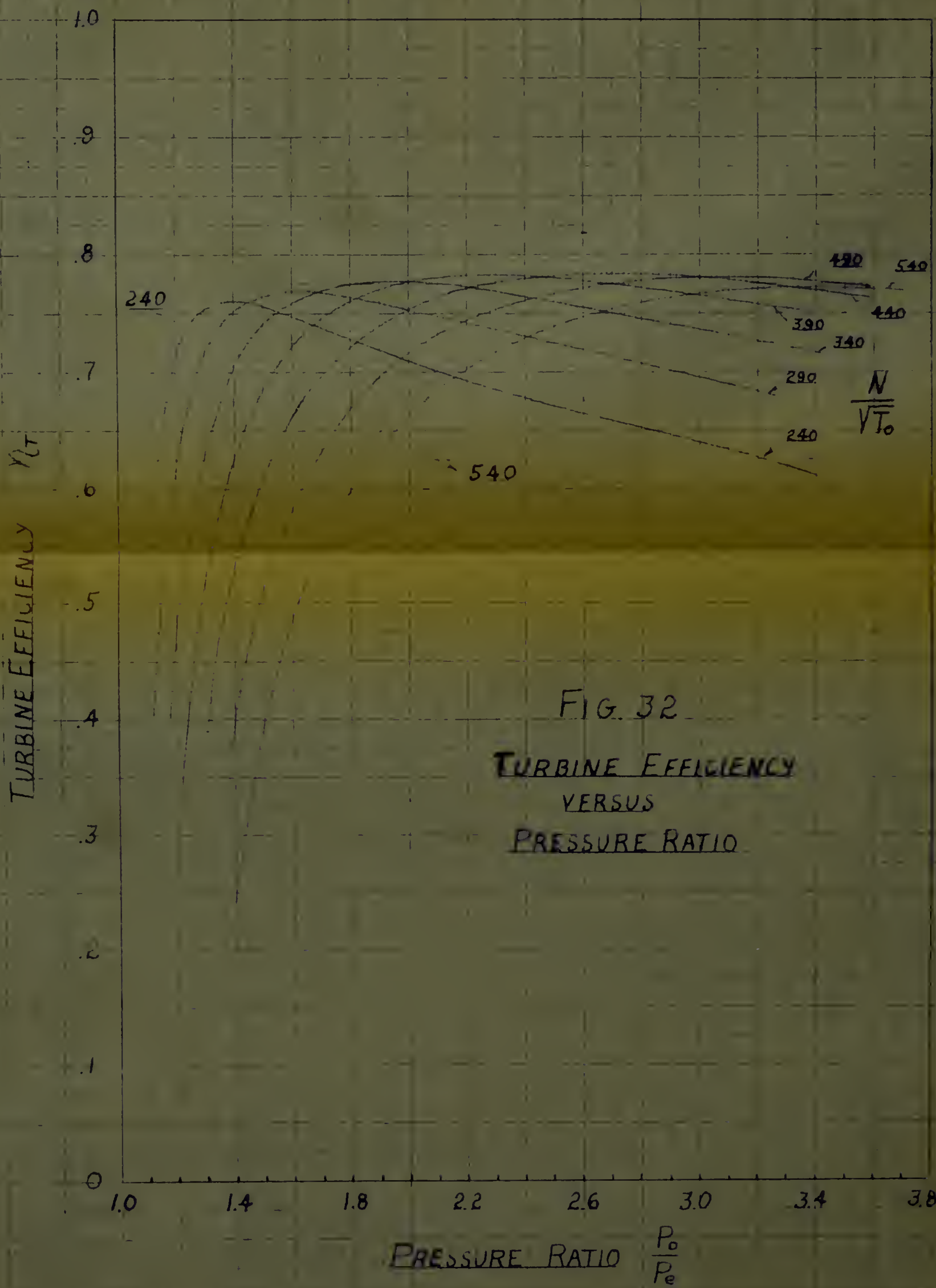


Fig. 32

Turbine Efficiency versus Pressure Ratio

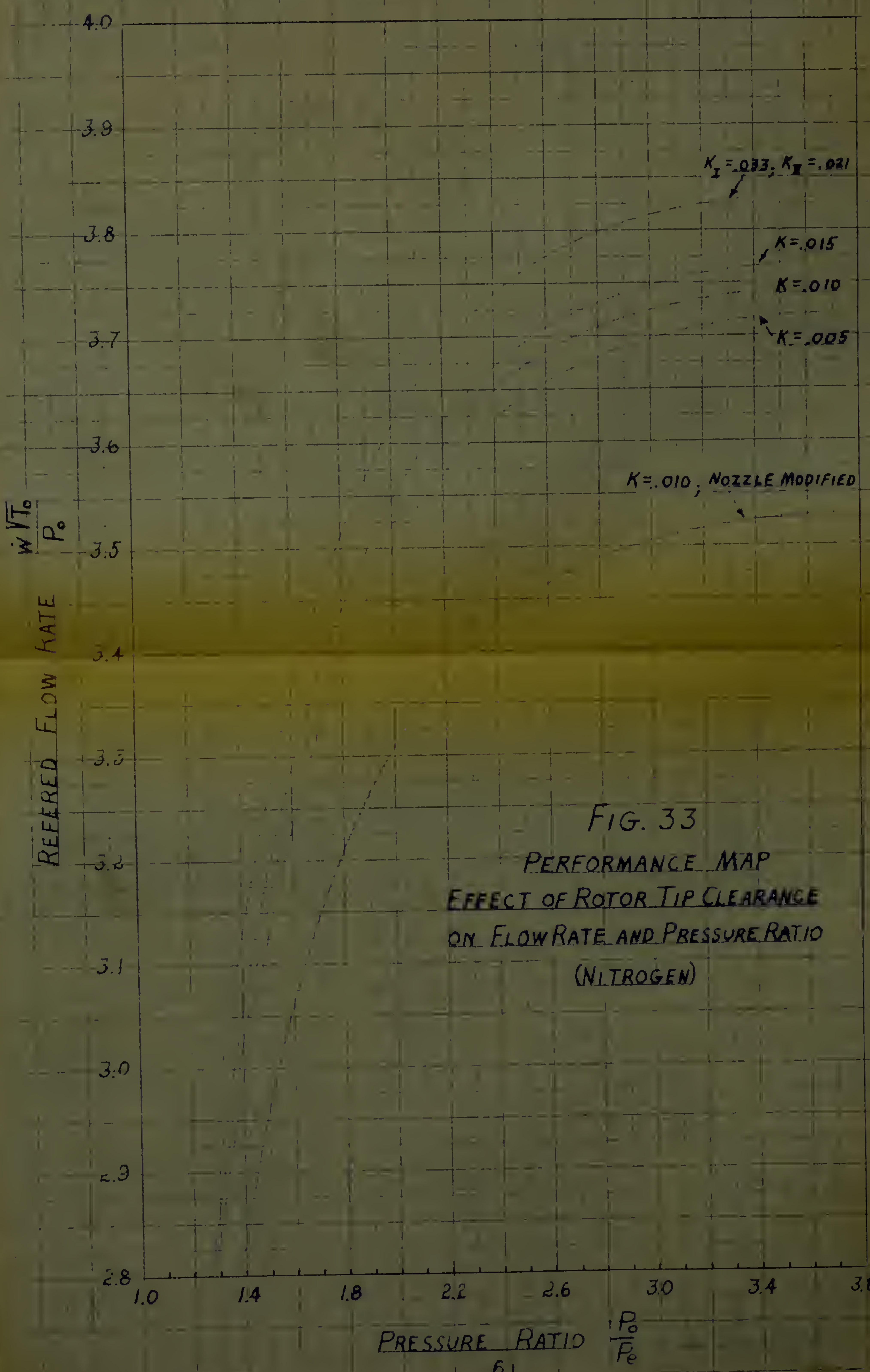


FIG. 33

PERFORMANCE MAP

EFFECT OF ROTOR TIP CLEARANCE ON FLOW RATE AND PRESSURE RATIO

(NITROGEN)

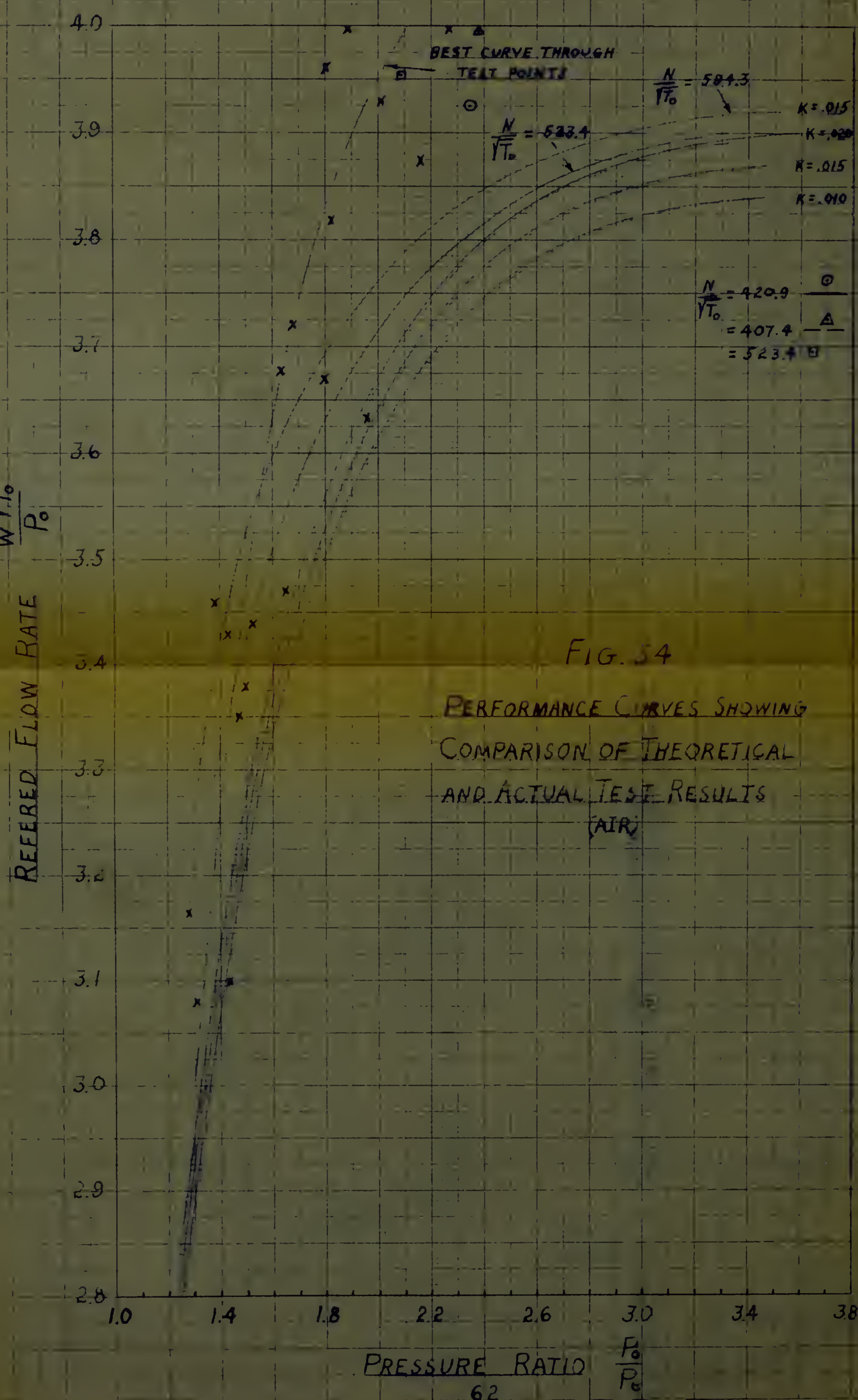


FIG. 54

PERFORMANCE CURVES SHOWING COMPARISON OF THEORETICAL AND ACTUAL TEST RESULTS (AIR)

FLOW FUNCTION FOR GAMMA = 1.36

TABLE IV

PRESSURE RATIO	ZETA = .000	.025	.050	.075	.100	.125	.150	.175	.200	.225	.250
1.00	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
1.02	.19588	.19339	.19088	.18833	.18575	.18314	.18048	.17779	.17506	.17229	.16947
1.04	.27141	.26794	.26443	.26088	.25728	.25363	.24993	.24618	.24238	.23851	.23459
1.06	.32580	.32161	.31737	.31307	.30873	.30432	.29985	.29533	.29073	.28607	.28134
1.08	.36886	.36408	.35925	.35436	.34940	.34438	.33930	.33414	.32891	.32361	.31823
1.10	.40450	.39922	.39388	.38848	.38301	.37748	.37187	.36619	.36042	.35458	.34865
1.12	.43476	.42905	.42327	.41743	.41152	.40553	.39947	.39333	.38711	.38080	.37440
1.14	.46089	.45480	.44864	.44241	.43610	.42972	.42327	.41672	.41009	.40337	.39655
1.16	.48374	.47730	.47080	.46422	.45757	.45083	.44402	.43712	.43012	.42304	.41585
1.18	.50389	.49715	.49033	.48343	.47646	.46941	.46228	.45505	.44774	.44032	.43281
1.20	.52179	.51476	.50765	.50048	.49322	.48588	.47845	.47094	.46333	.45562	.44780
1.22	.53776	.53047	.52311	.51567	.50815	.50055	.49286	.48507	.47720	.46922	.46113
1.24	.55208	.54455	.53695	.52927	.52151	.51367	.50573	.49771	.48958	.48136	.47302
1.26	.56496	.55721	.54939	.54149	.53350	.52544	.51728	.50903	.50068	.49223	.48367
1.28	.57657	.56862	.56059	.55249	.54430	.53603	.52767	.51921	.51066	.50200	.49323
1.30	.58707	.57893	.57071	.56241	.55404	.54558	.53702	.52838	.51963	.51078	.50182
1.32	.59657	.58825	.57986	.57139	.56283	.55419	.54547	.53664	.52772	.51869	.50955
1.34	.60518	.59670	.58814	.57951	.57079	.56198	.55309	.54410	.53502	.52582	.51652
1.36	.61300	.60436	.59565	.58686	.57799	.56903	.55998	.55084	.54160	.53226	.52280
1.38	.62009	.61131	.60245	.59352	.58450	.57540	.56622	.55693	.54755	.53806	.52846
1.40	.62653	.61761	.60862	.59955	.59041	.58117	.57185	.56243	.55292	.54330	.53357
1.42	.63238	.62334	.61422	.60502	.59575	.58639	.57694	.56740	.55776	.54802	.53817
1.44	.63769	.62853	.61929	.60997	.60058	.59111	.58154	.57188	.56213	.55227	.54231
1.46	.64251	.63323	.62388	.61445	.60495	.59536	.58569	.57593	.56606	.55610	.54602
1.48	.64687	.63749	.62803	.61850	.60889	.59920	.58943	.57956	.56960	.55953	.54936
1.50	.65082	.64134	.63178	.62215	.61245	.60266	.59279	.58283	.57277	.56261	.55234
1.52	.65440	.64481	.63517	.62544	.61565	.60577	.59580	.58575	.57561	.56536	.55501
1.54	.65762	.64795	.63821	.62840	.61851	.60855	.59850	.58837	.57814	.56781	.55737
1.56	.66052	.65076	.64094	.63105	.62108	.61103	.60091	.59069	.58038	.56998	.55947
1.58	.66312	.65328	.64338	.63341	.62336	.61324	.60304	.59275	.58237	.57189	.56131
1.60	.66544	.65553	.64555	.63551	.62539	.61520	.60492	.59457	.58412	.57357	.56292
1.62	.66751	.65753	.64748	.63736	.62718	.61692	.60658	.59615	.58564	.57503	.56432
1.64	.66934	.65929	.64918	.63900	.62875	.61842	.60802	.59753	.58696	.57629	.56552
1.66	.67096	.66084	.65066	.64042	.63011	.61972	.60926	.59872	.58809	.57736	.56654
1.68	.67236	.66219	.65195	.64165	.63128	.62084	.61032	.59972	.58904	.57826	.56738
1.70	.67358	.66335	.65305	.64269	.63227	.62178	.61121	.60056	.58982	.57900	.56807
1.72	.67462	.66433	.65398	.64357	.63310	.62255	.61194	.60124	.59046	.57959	.56862
1.74	.67550	.66516	.65476	.64430	.63377	.62318	.61252	.60177	.59095	.58004	.56903
1.76	.67622	.66583	.65538	.64488	.63431	.62367	.61296	.60218	.59131	.58036	.56931
1.78	.67681	.66637	.65587	.64532	.63471	.62403	.61328	.60245	.59155	.58056	.56947
1.80	.67725	.66677	.65623	.64564	.63498	.62426	.61348	.60261	.59167	.58065	.56953
1.82	.67757	.66705	.65647	.64584	.63514	.62439	.61356	.60266	.59169	.58063	.56948
1.84	.67778	.66721	.65660	.64593	.63520	.62440	.61354	.60261	.59161	.58052	.56934
1.86	.67788	.66727	.65662	.64591	.63515	.62432	.61343	.60247	.59143	.58032	.56911
1.88	.67787	.66723	.65654	.64580	.63500	.62415	.61323	.60224	.59117	.58003	.56880
1.90	.67777	.66709	.65637	.64560	.63477	.62389	.61294	.60192	.59083	.57966	.56841
1.92	.67758	.66687	.65612	.64532	.63446	.62355	.61257	.60153	.59042	.57923	.56795
1.94	.67730	.66657	.65578	.64495	.63407	.62313	.61213	.60107	.58993	.57872	.56742
1.96	.67695	.66618	.65537	.64452	.63361	.62265	.61162	.60054	.58938	.57815	.56684
1.98	.67652	.66573	.65489	.64401	.63308	.62209	.61105	.59994	.58877	.57752	.56619
2.00	.67603	.66521	.65435	.64344	.63249	.62148	.61042	.59929	.58810	.57683	.56549
2.20	.66812	.65711	.64607	.63500	.62389	.61273	.60153	.59028	.57898	.56762	.55619
2.40	.65674	.64563	.63450	.62335	.61217	.60096	.58972	.57844	.56711	.55573	.54430
2.60	.64361	.63247	.62131	.61014	.59896	.58775	.57652	.56526	.55397	.54263	.53126
2.80	.62971	.61857	.60743	.59629	.58514	.57397	.56279	.55159	.54037	.52911	.51783
3.00	.61561	.60450	.59341	.58232	.57122	.56013	.54903	.53791	.52678	.51563	.50445
3.20	.60163	.59058	.57955	.56853	.55752	.54651	.53550	.52448	.51346	.50243	.49137
3.40	.58796	.57699	.56604	.55510	.54418	.53326	.52236	.51146	.50055	.48964	.47873
3.60	.57472	.56383	.55296	.54212	.53130	.52049	.50970	.49891	.48814	.47736	.46658
3.80	.56196	.55116	.54038	.52964	.51892	.50823	.49755	.48689	.47624	.46559	.45495
4.00	.54970	.53899	.52832	.51768	.50707	.49648	.48593	.47539	.46487	.45436	.44386
4.20	.53795	.52733	.51676	.50623	.49573	.48526	.47482	.46441	.45402	.44364	.43328
4.40	.52670	.51618	.50571	.49528	.48489	.47454	.46422	.45393	.44367	.43343	.42320
4.60	.51593	.50551	.49515	.48482	.47455	.46431	.45411	.44394	.43380	.42369	.41360
4.80	.50563	.49531	.48505	.47483	.46466	.45454	.44445	.43441	.42440	.41441	.40446
5.00	.49578	.48556	.47539	.46528	.45522	.44521	.43524	.42531	.41542	.40557	.39574
5.20	.48635	.47622	.46616	.45615	.44620	.43629	.42644	.41663	.40686	.39712	.38742
5.40	.47731	.46728	.45732	.44741	.43757	.42777	.41803	.40833	.39868	.38906	.37949
5.60	.46866	.45872	.44886	.43905	.42931	.41962	.40998	.40040	.39086	.38136	.37190
5.80	.46036	.45052	.44075	.43104	.42140	.41181	.40228	.39280	.38338	.37400	.36466
6.00	.45240	.44265	.43297	.42336	.41382	.40433	.39491	.38554	.37622	.36695	.35772

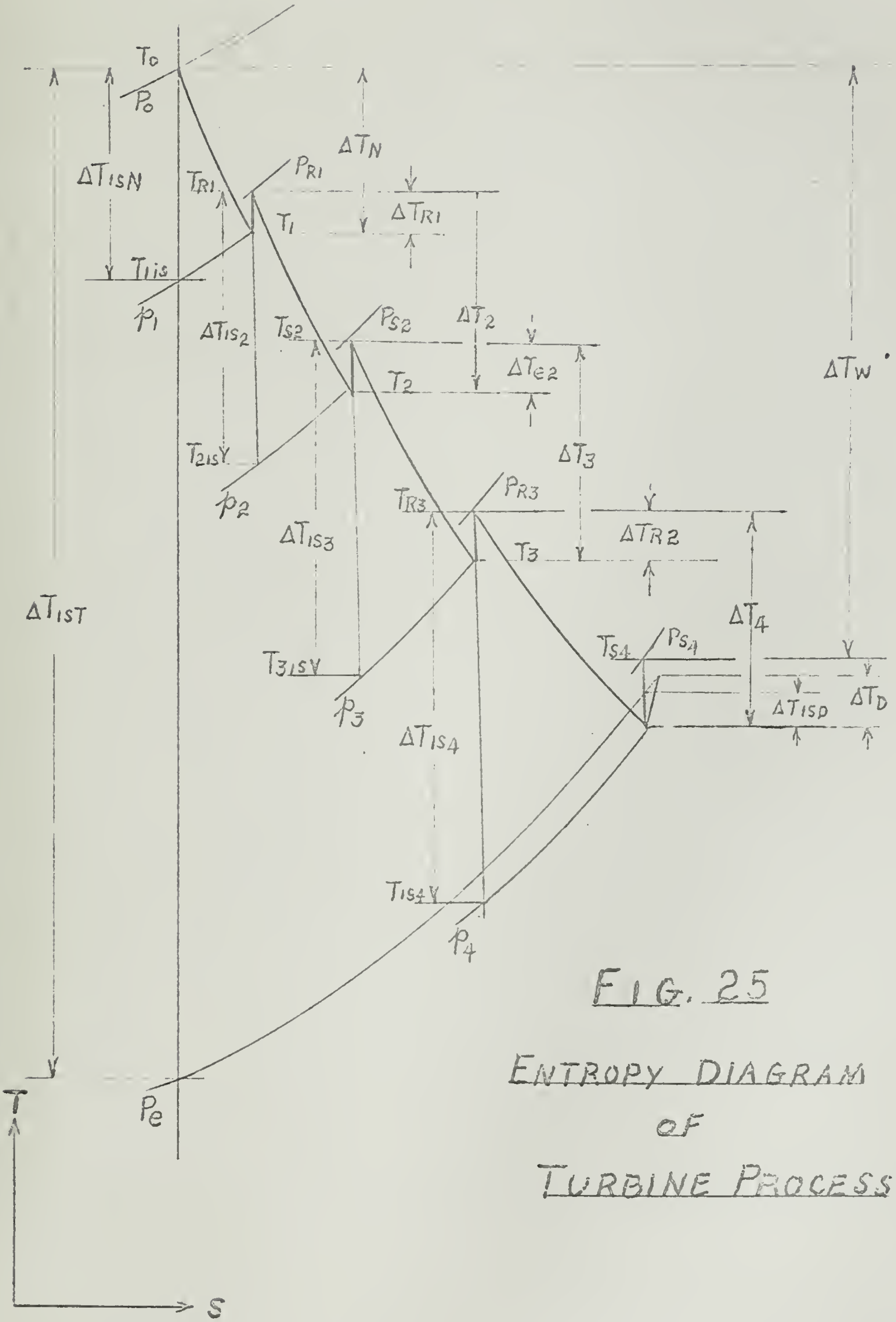


FIG. 25

ENTROPY DIAGRAM
OF
TURBINE PROCESS

TABLE I

BLADE DIMENSIONS AND ANGLES

		NOZZLE	ROTOR I	STATOR	ROTOR II
Inlet Diameter	in.	12.8	12.8	12.9	13.1
Discharge Diameter	in.	12.8	12.9	13.1	13.2
Mean Average Diameter	in.	12.8	12.85	13.0	13.15
Mean Blade Height	in.	.660	.705	.875	1.004
Radial Clearance	in.	0	.033	0	.021
Maximum Profile Thickness	in.	.100	.096	.093	.087
Trailing Edge Thickness	in.	.021	.036	.020	.034
Number of Blades		79	83	79	83
Throat "a"	in.	.190	.160	.1605	.1646
Throat Area	sq. in.	9.91	11.18	11.54	15.18
Chord	in.	.660	.760	.765	.765
Spacing at Mean Diameter	in.	.509	.4865	.517	.498
Inlet Blade Angle	deg.	-42.5	10.2	-23.5	8.3
Outlet Blade Angle	deg.	70.6	-70.3	72.6	-71.5

TABLE II

OPEN CYCLE TEST DATA

Working Fluid--Air;   Fuel for In-line Combustion--Methyl Alcohol

		TEST I	TEST II
Turbine Inlet Pressure	psia.	34.5	35.0
Turbine Outlet Pressure	psia.	14.7	14.7
Turbine Inlet Temperature	^oF	1090	1204
Turbine Outlet Temperature	^oF	825	917
Turbine Air Flow	lb/sec	3.35	3.30
Turbine Fuel Flow	lb/sec	.0901	.1027
Compressor Inlet Pressure	psia.	14.1	14.0
Compressor Outlet Pressure	psia.	36.5	37.0
Compressor Inlet Temperature	^oF	60	64
Compressor Outlet Temperature	^oF	281	284
Compressor Air Flow	lb/sec	3.559	3.490
Turbine Speed	rpm	16,570	16,620

Flow Areas as measured by the manufacturer assuming a radial tip clearance of .020 inches:

NOZZLE	10.32 sq. in.
ROTOR I	10.58 sq. in.
STATOR	11.72 sq. in.
ROTOR II	15.10 sq. in.

TABLE III

OPEN CYCLE TEST DATA

Working Fluid--Air

		TEST III	TEST IV
Turbine Overall Pressure Ratio		2.087	2.652
Turbine Inlet Temperature	°R	715.5	715.5
Refered Flow Rate		3.960	4.132
Refered RPM		523.4	594.3
Turbine Efficiency	%	81.57	84.00

Additional Test Points

Pressure Ratio	Ref. Flow Rate	Pressure Ratio	Ref. Flow Rate
1.28	3.17	1.82	3.82
1.31	3.08	1.88	4.00
1.38	3.46	1.96	3.63
1.43	3.10	2.01	3.93
1.43	3.43	2.16	3.875
1.47	3.50	2.27	4.00
1.50	3.38		
1.53	3.44		
1.63	3.68		
1.65	3.47		
1.68	3.72		
1.80	3.67		
1.80	3.96		

[illegible]

[illegible]

EFFECT. FLOW RATE	PRESSURE RATIO	OVERALL EFFICIENCY	VELOCITY RATIO	[illegible]	[illegible] RATIO	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2.700	1.1284	-3.776	1.2214	[illegible]	-16.9560	1.0313	1.1212	1.1435	1.1285	1.0097
2.720	1.1363	3.647	1.1955	[illegible]	9.1750	1.0377	1.1251	1.1501	1.1367	.9939
2.740	1.1455	9.310	1.1516	[illegible]	3.5204	1.0515	1.1291	1.1568	1.1456	.9900
2.760	1.1547	14.117	1.1197	[illegible]	2.4445	1.0541	1.1332	1.1631	1.1551	.9947
2.780	1.1644	18.861	1.0891	[illegible]	1.7705	1.0748	1.1373	1.1711	1.1640	.9925
2.800	1.1743	23.140	1.0507	[illegible]	1.4833	1.0765	1.1415	1.1785	1.1747	.9904
2.820	1.1844	27.050	1.0234	[illegible]	1.2884	1.0782	1.1457	1.1861	1.1847	.9871
2.840	1.1947	30.512	[illegible]	[illegible]	1.1527	1.0799	1.1501	1.1934	1.1952	.9857
2.860	1.2054	33.715	.9957	[illegible]	1.0525	1.1017	1.1544	1.2014	1.2057	.9835
2.880	1.2163	36.950	.9627	[illegible]	.9751	1.1035	1.1589	1.2077	1.2161	.9815
2.900	1.2275	39.771	.9417	[illegible]	.9141	1.1053	1.1634	1.2182	1.2262	.9790
2.920	1.2390	42.375	.9215	[illegible]	.8641	1.1072	1.1680	1.2268	1.2397	.9769
2.940	1.2508	44.763	.9023	[illegible]	.8231	1.1090	1.1727	1.2355	1.2515	.9742
2.960	1.2630	47.017	.8840	[illegible]	.7884	1.1109	1.1774	1.2444	1.2636	[illegible]
2.980	1.2755	49.117	.8665	[illegible]	.7535	1.1127	1.1823	1.2537	1.2764	[illegible]
3.000	1.2884	51.070	.8497	[illegible]	.7326	1.1146	1.1872	1.2631	1.2894	.9657
3.020	1.3015	52.938	.8335	[illegible]	.7096	1.1165	1.1921	1.2728	1.3027	.9643
3.040	1.3153	54.684	.8181	[illegible]	.6892	1.1184	1.1972	1.2826	1.3165	.9617
3.060	1.3287	56.341	.8037	[illegible]	.6721	1.1203	1.2023	1.2927	1.3302	.9592
3.080	1.3415	57.557	.7912	[illegible]	.6607	1.1222	1.2076	1.3020	1.3427	.9567
3.100	1.3543	58.759	.7791	[illegible]	.6502	1.1250	1.2127	1.3113	1.3559	.9545
3.120	1.3675	60.121	.7675	[illegible]	.6408	1.1272	1.2184	1.3208	1.3692	.9521
3.140	1.3810	61.306	.7563	[illegible]	.6317	1.1293	1.2237	1.3306	1.3827	.9497
3.160	1.3943	62.479	.7453	[illegible]	.6230	1.1315	1.2295	1.3405	1.3969	.9473
3.180	1.4093	63.542	.7347	[illegible]	.6163	1.1336	1.2353	1.3507	1.4112	.9449
3.200	1.4235	64.533	.7245	[illegible]	.6092	1.1361	1.2411	1.3609	1.4257	.9424
3.220	1.4385	65.521	.7146	[illegible]	.6026	1.1384	1.2471	1.3716	1.4411	.9399
3.240	1.4538	66.416	.7048	[illegible]	.5964	1.1407	1.2531	1.3823	1.4566	.9373
3.260	1.4696	67.327	.6953	[illegible]	.5904	1.1431	1.2593	1.3934	1.4726	.9348
3.280	1.4860	68.124	.6859	[illegible]	.5843	1.1456	1.2657	1.4048	1.4894	.9322
3.300	1.5043	68.930	.6762	[illegible]	.5768	1.1480	1.2722	1.4175	1.5077	.9294
3.320	1.5233	69.703	.6665	[illegible]	.5695	1.1505	1.2789	1.4307	1.5274	.9265
3.340	1.5432	70.430	.6570	[illegible]	.5625	1.1531	1.2856	1.4444	1.5476	.9236
3.360	1.5637	71.125	.6478	[illegible]	.5558	1.1557	1.2926	1.4585	1.5687	.9206
3.380	1.5852	71.770	.6387	[illegible]	.5493	1.1583	1.2996	1.4731	1.5900	.9176
3.400	1.6075	72.456	.6298	[illegible]	.5431	1.1610	1.3069	1.4882	1.6135	.9145
3.420	1.6307	73.036	.6211	[illegible]	.5369	1.1637	1.3143	1.5039	1.6374	.9113
3.440	1.6549	[illegible]	.6125	[illegible]	.5310	1.1665	1.3219	1.5201	1.6623	.9081
3.460	1.6804	74.173	.6040	[illegible]	.5249	1.1693	1.3297	1.5370	1.6887	.9048
3.480	1.7070	74.741	.5957	[illegible]	.5191	1.1722	1.3377	1.5545	1.7162	.9014
3.500	1.7352	75.274	.5874	[illegible]	.5131	1.1751	1.3459	1.5729	1.7455	.8978
3.520	1.7649	75.767	.5792	[illegible]	.5074	1.1781	1.3542	1.5922	1.7764	.8942
3.540	1.7961	76.318	.5711	[illegible]	.5017	1.1812	1.3628	1.6122	1.8089	.8904
3.560	1.8272	76.808	.5631	[illegible]	.4961	1.1843	1.3717	1.6333	1.8437	.8865
3.580	1.8645	77.279	.5551	[illegible]	.4904	1.1874	1.3808	1.6553	1.8807	.8825
3.600	1.9015	77.735	.5471	[illegible]	.4846	1.1907	1.3902	1.6786	1.9202	.8784
3.620	1.9417	78.168	.5392	[illegible]	.4789	1.1939	1.3998	1.7031	1.9620	.8741
3.640	1.9848	78.542	.5312	[illegible]	.4729	1.1973	1.4097	1.7291	2.0085	.8696
3.660	2.0314	78.970	.5233	[illegible]	.4668	1.2007	1.4199	1.7565	2.0584	.8649
3.680	2.0823	79.335	.5152	[illegible]	.4606	1.2042	1.4305	1.7861	2.1131	.8600
3.700	2.1384	79.658	.5069	[illegible]	.4540	1.2077	1.4414	1.8175	2.1737	.8548
3.720	2.2012	79.965	.4985	[illegible]	.4470	1.2113	1.4527	1.8515	2.2419	.8493
3.740	2.2715	80.223	.4898	[illegible]	.4397	1.2150	1.4643	1.8880	2.3184	.8434
3.760	2.3524	80.437	.4808	[illegible]	.4317	1.2188	1.4765	1.9279	2.4066	.8370
3.780	2.4477	80.572	.4712	[illegible]	.4230	1.2226	1.4890	1.9716	2.5107	.8300
3.800	2.5637	80.614	.4608	[illegible]	.4131	1.2266	1.5020	2.0201	2.6375	.8222
3.820	2.7128	80.576	.4492	[illegible]	.4016	1.2306	1.5156	2.0752	2.7996	.8131
3.840	2.9250	80.093	.4352	[illegible]	.3872	1.2347	1.5296	2.1381	3.0300	.8019
3.860	3.3324	78.314	.4143	[illegible]	.3644	1.2389	1.5444	2.2125	3.4694	.7150

3.880 FLOW IS CHOKED IN BLADE ROW NO. [illegible]

TIME, 3 MINUTES AND 14 SECONDS

APPENDIX I

Development of Equations

I. Development of expression for the Polytropic Exponent

in terms of ζ_e

The efficiency of the flow process from the inlet to the minimum area of a blade row is equivalent to $(1 - \zeta_e)$ and can be expressed in terms of the temperature ratio dT/dT_{is} as

$$\eta = dT/dT_{is} = 1 - \zeta_e$$

In general

$$(T - dT_{is})/T = ((p - dp)/p)^{\frac{\gamma-1}{\gamma}}$$

$$1 - dT_{is}/T = (1 - dp/p)^{\frac{\gamma-1}{\gamma}}$$

Expressing the right side of the equation in series form $(1 - \varepsilon)$

$$1 - dT_{is} = 1 - (\gamma - 1)/\gamma \; dp/p$$

or $$dT_{is}/T = (\gamma - 1)/\gamma \; dp/p$$

Since

$$dT = dT_{is}$$

then $$dT/T = \eta(\gamma - 1)/\gamma \; dp/p$$

Intergrating

$$\ln T = \ln p^{\eta\frac{\gamma-1}{\gamma}} + \text{Constant}$$

thus $$T = p^{\eta\frac{\gamma-1}{\gamma}}$$

In order to express this relation in the form of PV^n = Constant for a polytropic process

$$\eta(\gamma - 1)/\gamma = (1 - \zeta_e)(\gamma - 1)/\gamma = (n - 1)/n$$

or $$1/n = ((1 - \zeta_e)(\gamma - 1) + \gamma)/\gamma$$

and $$n = \gamma/(\zeta_e(\gamma - 1) + 1)$$

II. Derivation of the equation for the Approximate Pressure Ratio across a Blade Row:

The Flow Function was defined as

$$\Phi = \frac{w\sqrt{T_o}}{P_o}\frac{\sqrt{R/g}}{A_e} = \sqrt{\frac{2\gamma}{(\gamma - 1)}\left[\left(\frac{p}{P_o}\right)^{2/n} - \left(\frac{p}{P_o}\right)^{(n+1)/n}\right]}$$

The ratio p/P_o is equivalent to $(P_o - \Delta p)/P_o$ or $1 - \Delta p/P_o$.

Expressing the exponential terms in a binomial series expansion

$$(p/P_o)^{2/n} = 1 - \frac{2}{n}\frac{\Delta p}{P_o} + \frac{(2/n - 1)}{n}\left(\frac{\Delta p}{P_o}\right)^2 \cdots\cdots\cdots$$

$$(p/P_o)^{(n+1)/n} = 1 + \frac{n+1}{n}\;\frac{p}{P_o} + \frac{n+1}{2n^2}\left(\frac{\Delta p}{P_o}\right)^2 \cdots\cdots\cdots$$

Substituting the series expressions in the Flow Function Equation and reducing

$$\Phi = \sqrt{\frac{2\gamma}{(\gamma - 1)}\left[\frac{n-1}{n}\frac{\Delta p}{P_o} + \frac{3}{2}\left(\frac{1-n}{n^2}\right)\left(\frac{\Delta p}{P_o}\right)^2\right]}$$

Solving for $\Delta p/P_o$ and reducing

$$\Delta p/P_o = \frac{n}{3}\left[1 - \sqrt{1 - 3\,\frac{(\gamma - 1)}{\gamma}\,\frac{\Phi^2}{(n-1)}}\right]$$

so for a 1st approximation P_o/p can be expressed as

$$P_o/p = \frac{1}{1 - \Delta p/P_o} = 1/\left\{1 - \frac{n}{3}\left[1 - \sqrt{1 - 3\,\frac{(\gamma - 1)}{\gamma}\,\frac{\Phi^2}{(n-1)}}\right]\right\}$$

III. Sample calculation of the specific heat ratio and the gas constant of the combustion gases produced by the combustion of Methyl Alcohol and Air.

For Test I: Fuel Flow = .0901 lbs/sec

Air Flow = 3.35 lbs/sec

M. W. of CH_4OH = 33.0

M. W. of Air = 28.97

A/F = 3.35/.0901 = 37.2 lbs Air/lb Fuel = 42.35 mols Air/mol Fuel

Basis: 1 mol Fuel

$CH_4OH + 8.9\ O_2 + 33.45\ N_2$ ---- $CO_2 + 2.5\ H_2O + 8.15\ O_2 + 33.45\ N_2$

20.8 Oxygen atoms available 4.5 Oxygen atoms required

Therefore 20.8 - 4.5 = 16.3 Oxygen atoms excess

or 362% excess Air

By entering Table 5 of Ref. 5 with the average temperature of 1420 °R a specific heat ratio of 1.344 can be obtained.

The average mol. wt. of the products of combustion was found to be 28.7. By dividing this average into the universal gas constant (mR = 1545) a value of R of 53.9 was obtained.

APPENDIX II

Loss Coefficients

Sample Calculations & Tables

EQUATIONS AND CALCULATIONS INVOLVED IN LOSS COMPUTATIONS FOR NOZZLE

From Blade Profiles: $s = .509$; $c = .660$; $t = .100$; $t_e = .021$;

$a = .190$; $\alpha_1^* = 70.6^\circ$; $\alpha_o^* = -42.5$;

$s/c = .771$; $t/c = .1516$; $t_e/a = .1104$

From Turbine Drawing: $h = .660$ in.

$$\alpha_1 = \cos^{-1} a/(s - t_e/\cos\alpha_1^*) = \cos^{-1} .190/(.509 - .021/\cos 70.6)$$

$$= 64.8^\circ$$

$$Y_{p(i=0)} = \left\{Y_{p(\alpha_o^*=0)} + \left(\frac{\alpha_o^*}{\alpha_1}\right)^2\left[Y_{p(\alpha_o^*=-\alpha_1)} - Y_{p(\alpha_o^*=0)}\right]\right\}\left(\frac{t/c}{.2}\right)^{-\left(\frac{\alpha_o^*}{\alpha_1}\right)} =$$

$$= \left\{.030 + \left(\frac{-42.5}{64.8}\right)^2\left[.126 - .030\right]\right\}\left(\frac{.1516}{.2}\right)^{-\left(\frac{-42.5}{64.8}\right)} = .0634$$

$$\alpha_{1(s/c=.75)} = \alpha_1/.995 = 64.8/.995 = 65.0^\circ$$

$$\alpha_o^*/\alpha_{1(s/c=.75)} = -42.5/65 = -.654; \qquad i_{s(s/c=.75)} = 20.0$$

$$\Delta i_s = -1.2; \qquad i_s = 20.0 + (-1.2) = 18.8^\circ$$

$$i/i_s = -42.5/18.8 = -2.26; \qquad Y_p/Y_{p(i=0)} = 3.15; \quad Y_{p(i=-42.5)} = .1995$$

$$\zeta_p = Y_p/(1 + Y_p) = .1995/(1 + .1995) = .1670$$

$$\vartheta = 1.2/(1.2 + \zeta_p) = 1.2/(1.2 + .1670) = .879$$

$$\leq\delta^*/a = \zeta_p/(1.2 + \zeta_p) = .1670/(1.2 + .1670) = .122$$

$$\zeta_e = .9(1 - \vartheta^2) = .9 \times (1 - .897^2) = .2050$$

$$A_1 = \pi D_1 h_1 \cos\alpha_o^* = 3.14 \times 12.8 \times .66 \times .737 = 19.58$$

$$A_2 = \pi D_2 h_2 \cos\alpha_1 = 3.14 \times 12.8 \times .66 \times .425 = 11.30$$

$$\lambda = f\left[\frac{(A_2/A_1)^2}{1 + (ID/OD)}\right] = f\left[\frac{(11.3/19.58)^2}{1 + (12.8/12.8)}\right] = f\left[.167\right]$$

$= .0076$ from Fig.___

$$\alpha_m = \tan^{-1}(\tan\alpha_o + \tan\alpha_1)/2 = \tan^{-1}(0 + 2.13)/2 = 46.8^\circ$$

$$Y_{s(i=-42.5)} = 4\lambda(\cos^2\alpha_1/\cos\alpha_m)(\tan\alpha_o - \tan\alpha_1)^2$$

$$= 4 \times .0076 \times (.181/.685) \times (0 - 2.13)^2 = .0364$$

$$\zeta_s = Y_s/(1 + Y_s) = .0364/(1 + .0364) = .0351$$

$$\zeta_{te} = .3(t_e/a)(\zeta_p/\leq\delta^*/a) = .3 \times .1104 \times .167/.122 = .0454$$

$$\zeta_{total} = \zeta_p + \zeta_s + \zeta_{te} = .1670 + .0351 + .0454 = .2475$$

EQUATIONS AND CALCULATIONS INVOLVED IN LOSS COMPUTATIONS FOR ROTOR I

From Blade Profiles: $s = .4865$; $c = .760$; $t = .096$; $t_e = .036$;

$a = .160$; $\beta_2^* = -70.8$; $\beta_1^* = 10.2$

$s/c = .639$; $t/c = .1263$; $t_e/a = .225$

From Turbine Drawing: $k_{(cold)} = .033$; $h = .705$

- -

$$\beta_2 = \cos^{-1} a/(s - t_e/\cos\beta_2^*) = \cos^{-1} .160/(.4865 - .036/\cos-70.8) =$$

$$= -64.9^\circ$$

$$Y_p(i = 0) = \left\{Y_p(\beta_1^* = 0) + \left(\frac{\beta_1^*}{\beta_2}\right)^2\left[Y_p(\beta_1^* = -\beta_2) - Y_p(\beta_1^* = 0)\right]\right\}\left(\frac{t/c}{.2}\right)^{-\left(\frac{\beta_1^*}{\beta_2}\right)}$$

$$= \left\{.034 + \left(\frac{10.2}{-64.9}\right)^2\left[.117 - .034\right]\right\}\left(\frac{.1263}{.2}\right)^{-\left(\frac{10.2}{-64.9}\right)} = .036 \times .93 = .0335$$

$$\beta_{2(s/c = .75)} = \beta_2/1.035 = -64.9/1.035 = -62.7^\circ$$

$$\beta_1^*/\beta_{2(s/c = .75)} = 10.2/-62.7 = -.163; \quad i_{s(s/c = .75)} = 35.0^\circ$$

$$\Delta i_s = 3.5^\circ; \qquad i_s = 35.0^\circ + 3.5^\circ = 38.5^\circ$$

$$\zeta_p = Y_p/(1 + Y_p) = .0335/(1 + .0335) = .0324$$

$$\vartheta = 1.2/(1.2 + \zeta_p) = 1.2/(1.2 + .0324) = .974$$

$$\zeta_e = .9\,(1 - \vartheta^2) = .9 \times (1 - .974^2) = .046$$

$$\leq\delta^*/a = \zeta_p/(1.2 + \zeta_p) = .0324/(1.2 + .0324) = .0262$$

$$A_1 = \pi D_1 h_1 \cos\beta_1^* = 3.14 \times 12.8 \times .66 \times \cos 10.2^\circ = 26.1$$

$$A_2 = \pi D_2 h_2 \cos\beta_2 = 3.14 \times 12.9 \times .75 \times \cos 64.9^\circ = 12.9$$

$$\lambda = f\left[\frac{(A_2/A_1)^2}{1 + (ID/OD)}\right] = f\left[\frac{(12.9/26.1)^2}{1 + (12.8/12.9)}\right] = f\left[.123\right]$$

$= .0068$ from Fig. __

Equations for Y_s and Y_k hold between -1.5 and 1.0 i/i_s: (See Ref. 6)

$$Y_s = 4\lambda(\cos^2\beta_2/\cos\beta_m)(\tan\beta_1 - \tan\beta_2)^2 =$$

$$= 4 \times .0068 \times (.180/.690) \times (0 - (-2.11))^2 = .0316$$

$$Y_k = 2\,k/h\,(\cos^2\beta_2/\cos\beta_m)\,(\tan\beta_1 - \tan\beta_2)^2 =$$

$$= 2 \times .033/.705\,(.180/.690)\,(0 - (-2.11))^2 = .109$$

where $\beta_m = \tan^{-1}((\tan\beta_1 + \tan\beta_2)/2) = \tan^{-1}(-1.055) = -46.4$

$$\zeta_s = Y_s/(1 + Y_s) = .0316/(1 + .0316) = .0306$$

$$\zeta_k = Y_k/(1 + Y_k) = .1090/(1 + .1090) = .0990$$

$$\zeta_{te} \quad .3(t_e/a)(\zeta_p/\Sigma\zeta^*/a) = .3 \times .225 \times .0324/.0262 = .0835$$

$$\zeta_{total} = \zeta_p + \zeta_s + \zeta_k + \zeta_{te} = .0324 + .0306 + .0990 + .0835 = .2460$$

TABLE V

ROTOR I LOSS COEFFICIENTS

β_1	70	60	50	40	30	20	10	00	-10	-20	-30	-40	-50	-60	-70
i	-59.8	-49.8	-39.8	-29.8	-19.8	-9.8	.2000	10.2	20.2	30.2	40.2	50.2	60.2	70.2	80.2
i/i_s	-1.55	-1.29	-1.03	-.775	-.515	-.245	.0052	.2650	.5250	.7850	1.040	1.305	1.560	1.820	2.080
$Y_P/Y_P(i = 0)$	2.18	1.87	1.60	1.38	1.20	1.07	1.00	1.00	1.20	1.75	2.16	3.40	4.80		
Y_P	.0730	.0626	.0536	.0462	.0402	.0358	.0335	.0335	.0402	.0550	.0775	.1140	.1610		
ζ_P	.0680	.0590	.0510	.0442	.0387	.0346	.0324	.0324	.0386	.0520	.0720	.1024	.1387		
φ	.947	.953	.960	.964	.970	.972	.974	.974	.970	.956	.947	.921	.895		
$\Sigma\delta^*/a$	.0536	.0469	.0408	.0355	.0313	.0280	.0262	.0262	.0312	.0441	.0532	.0785	.1035		
ζ_e	.0926	.0828	.0710	.0640	.0530	.0495	.0460	.0460	.0530	.0725	.0976	.1350	.1750		
ζ_{te}	.0856	.0850	.0845	.0841	.0835	.0835	.0835	.0835	.0835	.0849	.0856	.0880	.0905		
β_m	17.5	-10.8	-24.7	-32.4	-37.4	-41.2	-44.0	-46.4	-49.0	-51.0	-53.4				
Y_s	.1210	.0740	.0588	.0505	.0446	.0398	.0357	.0316	.0280	.0238	.0193	.0193	.0193		
ζ_s	.1080	.0690	.0560	.0480	.0427	.0383	.0345	.0306	.0273	.0232	.0189	.0189	.0189		
Y_k	.4160	.2450	.2020	.1735	.1530	.1370	.1230	.1090	.0960	.0820	.0660	.0660	.0660		
ζ_k	.2940	.2020	.1680	.1480	.1320	.1210	.1100	.0990	.0880	.0758	.0620	.0620	.0620		
ζ_{total}	.5560	.4150	.3590	.3240	.2970	.2770	.2600	.2460	.2370	.2370	.2470	.2710	.3100		

TABLE VI

STATOR LOSS COEFFICIENTS

α_2	-70	-60	-50	-40	-30	-20	-10	00	10	20	30	40	50	60	70
i	46.5	36.5	26.5	16.5	6.5	-3.5	-13.5	-23.5	-33.5	-43.5	-53.5	-63.5	-73.5	-83.5	-93.5
i/i_s	1.28	1.01	.73	.46	.20	-.10	-.37	-.65	-.93	-1.20	-1.48	-1.75	-2.02	-2.30	-2.58
$Y_p/Y_{p(i=0)}$	2.90	2.06	1.44	1.12	1.00	1.00	1.10	1.30	1.52	1.75	2.07	2.40	2.78	3.19	3.60
Y_p	.1210	.0855	.0600	.0465	.0415	.0415	.0456	.0540	.0630	.0726	.0860	.0995	.1152	.1323	.1492
ζ_p	.1080	.0786	.0566	.0445	.0400	.0400	.0436	.0512	.0591	.0684	.0792	.0905	.1035	.1170	.1300
φ	.920	.940	.956	.964	.968	.968	.964	.959	.954	.947	.940	.930	.921	.912	.902
$\Sigma\delta^*/a$	.0705	.0615	.0451	.0357	.0322	.0322	.0350	.0410	.0470	.0540	.0620	.0700	.0795	.0890	.0977
ζ_c	.1400	.1040	.0765	.0630	.0575	.0575	.0620	.0730	.0820	.0930	.1090	.1210	.1385	.1510	.1680
ζ_{te}	.0483	.0478	.0470	.0466	.0465	.0465	.0466	.0467	.0470	.0473	.0478	.0483	.0486	.0491	.0498
α_m		23.3	35.0	41.3	45.3	48.3	50.4	52.5	54.3	56.0	57.8				
Y_s	.0661	.0661	.0568	.0510	.0464	.0427	.0380	.0360	.0324	.0289	.0248	.0248	.0248	.0248	.0248
ζ_s	.0620	.0620	.0538	.0485	.0445	.0410	.0366	.0348	.0314	.0281	.0242	.0242	.0242	.0242	.0242
Y_k	.0000														
ζ_k	.0000														
ζ_{total}	.2180	.1884	.1574	.1396	.1310	.1275	.1268	.1327	.1375	.1438	.1512	.1630	.1763	.1903	.2040

TABLE VII

ROTOR II LOSS COEFFICIENTS

β_3	70	60	50	40	30	20	10	00	-10	-20	-30	-40	-50	-60	-70
i	-61.7	-51.7	-41.7	-31.7	-21.7	-11.7	-1.7	8.30	18.3	28.3	38.3	48.3	58.3	68.3	78.3
i/i_s	-1.60	-1.34	-1.08	-.82	-.56	-.303	-.044	.215	.475	.734	.9900	1.250	1.510	1.770	2.030
$Y_p/Y_{p(i=0)}$	2.20	1.90	1.63	1.43	1.22	1.10	1.00	1.00	1.12	1.46	2.00	3.00	4.51		
Y_p	.0685	.0591	.0507	.0445	.0380	.0342	.0311	.0311	.0349	.0455	.0622	.0934	.1400		
ζ_p	.0641	.0558	.0482	.0426	.0356	.0331	.0302	.0302	.0337	.0435	.0585	.0855	.1230		
φ	.949	.955	.962	.965	.971	.972	.975	.975	.972	.965	.955	.934	.906		
$\Sigma\delta^{*}/a$	.0507	.0445	.0387	.0343	.0288	.0268	.0246	.0240	.0271	.0350	.0465	.0655	.0930		
ζ_e	.0900	.0765	.0657	.0620	.0486	.0485	.0440	.0440	.0485	.0620	.0810	.1130	.1580		
ζ_{te}	.0785	.0777	.0771	.0770	.0766	.0765	.0760	.0760	.0771	.0771	.0780	[illegible]	.0820		
β_m	16.7	-11.6	-25.4	-33.0	-38.0	-41.7	-44.4	-47.0	-49.3	-51.4	-53.7				
Y_s	.1150	.0710	.0570	.0490	.0435	.0390	.0350	.0310	.0272	.0235	.0190	.0190	.0190	.0190	.0190
ζ_s	.1030	.0660	.0540	.0480	.0420	.0380	.0340	.0300	.0270	.0230	.0190	.0190	.0190	.0190	.0190
Y_k	.1850	.1140	.0915	.0790	.0700	.0624	.0563	.0500	.0438	.0377	.0306	.0306	.0306	.0306	.0306
ζ_k	.1560	.1023	.0838	.0731	.0654	.0580	.0534	.0476	.0420	.0364	.0297	.0297	.0297	.0297	[illegible]
ζ_{total}	.4020	.3020	.2650	.2410	.2200	.2060	.1940	.1840	.1800	.1800	.1860	.2150	.2540		

APPENDIX III

Basic Fortran Program

Table of Fortran Names and Symbols

Flow Charts

FORTRAN NAMES, EQUIVALENT SYMBOLS, AND DEFINITIONS

A		Intermediate step in calculation of the Approximate pressure ratio across a blade row.
ALPHAI	$\alpha(0,2)$	Angle of absolute velocity at inlet to Nozzle or Stator.
ALPHAO	$\alpha(1,3)$	Angle of absolute velocity at exit from Nozzle or Stator.
AR	$A_e(2,4)$	Minimum flow area between rotor blades.
AS	$A_e(1,3)$	Minimum flow area between stator blades.
BETAI	$\beta(1,3)$	Angle of relative velocity at inlet of Rotor.
BETAO	$\beta(2,4)$	Angle of relative velocity at exit from Rotor.
C1	C_1	Constant; See Sample Calculations
C2	C_2	Constant; See Sample Calculations
C3	C_3	Constant; See Sample Calculations
CP	C_p	Specific heat at constant pressure.
DIFF		Difference
DIFFU		Diffusor
DMI	$D_m(1,3)$	Mean diameter at inlet to rotor blade row.
DMO	$D_m(2,4)$	Mean diameter at exit from rotor blade row.
DTD	$\Delta T_{isD}/T_o$	Isentropic temperature drop through the diffusor.
DTISO	$\Delta T_{is}/T_o$	Isentropic temperature drop across a blade row.
DTO	$\Delta T/T_o$	Actual temperature drop across a blade row.
DTR	$\Delta T_R/T_o$	Temperature rise due to the kenetic energies of the relative and perpheral velocities pertaining to the rotor.
DTS	$\Delta T_S/T_o$	Temperature rise due to the kenetic energy of the absolute velocity of the flow leaving the rotor.

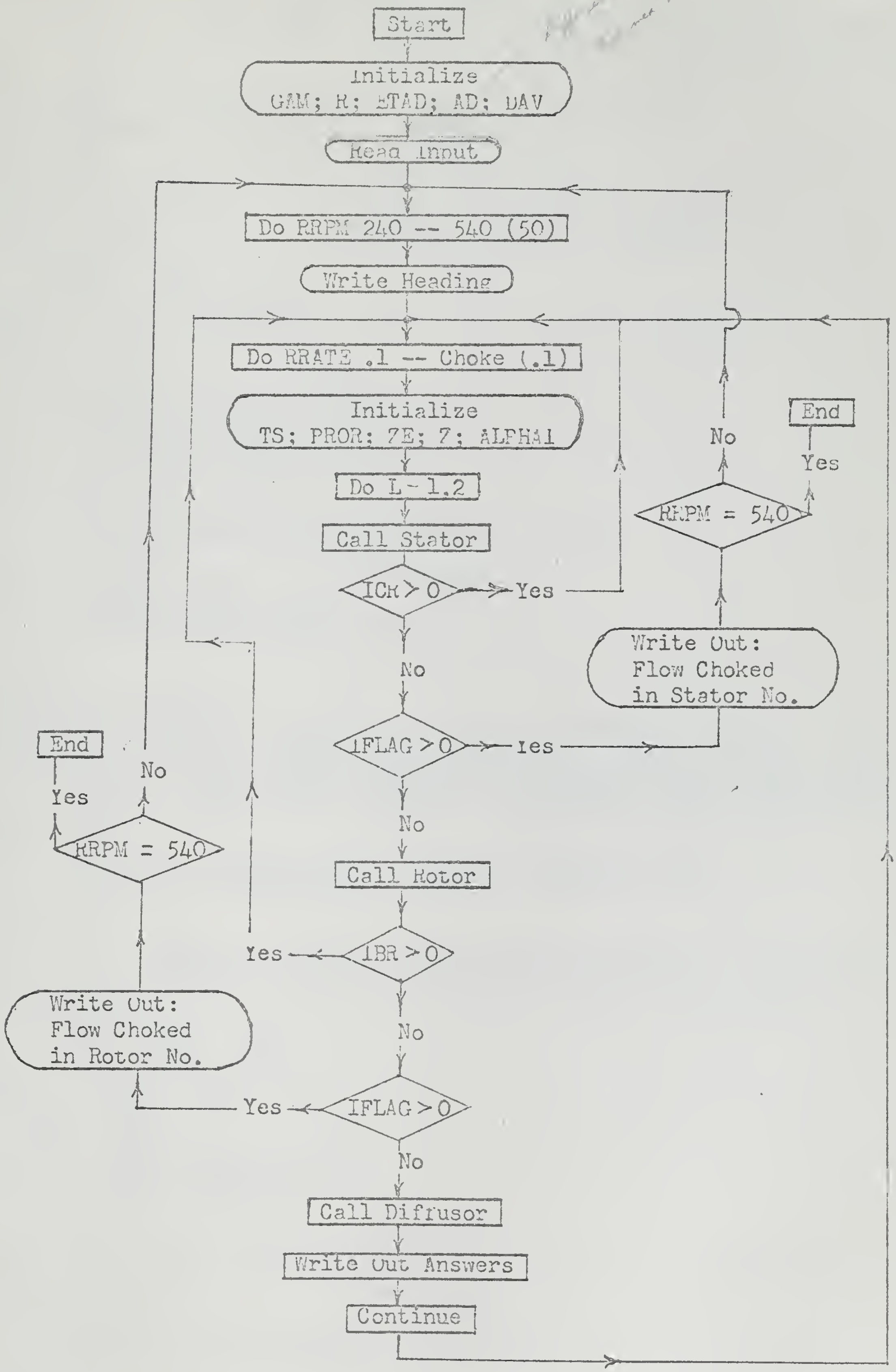
DTT	$\Delta T_{isT}/T_o$	Isentropic temperature drop through the turbine.
DUG	$1/(P/p)^{m2}$	Intermediate step in the calculation of an Approximate Flow Function.
DUGM	$1/(P/p)_c^{m2}$	Intermediate step in the calculation of the critical value of the Flow Function.
DUN	$1/(P/p)^{m1}$	Intermediate step in the calculation of an Approximate Flow Function.
DUNM	$1/(P/p)_c^{m1}$	Intermediate step in the calculation of the critical value of the Flow Function.
DTW	$\Delta T_w/T_o$	Actual temperature drop across the turbine blade rows.
EN	n	Polytropic exponent
ETAD	η_D	Diffusor efficiency for ideal axial exit of the flow.
ETADA	η_A	Actual diffusor efficiency.
ETAT	η_T	Overall turbine efficiency.
EXP1	$2/n$	Pressure ratio exponent for polytropic process.
EXP2	$(n + 1)/n$	Pressure ratio exponent for polytropic process.
EXP3	m_1	Pressure ratio exponent for isentropic process.
EXP4	m_2	Pressure ratio exponent for isentropic process.
EXP5	$n/(n + 1)$	Pressure ratio exponent for polytropic process.
GAM	γ	Specific heat ratio (C_p/C_v).
IBR		Flag allowing decision for control branching.
ICR		Flag allowing decision for control branching.
IFLAG		Flag allowing decision for control branching.
L		Pass or stage number.
OT	Φ_A	Value of flow function corresponding to the approximate pressure ratio.

OTA	Φ	Flow Function for a blade row.
OTM	Φ_M	Maximum value of the flow function for a blade row; choking occurs.
P	p/P_o	Ratio of the static pressure after a row of blades to the turbine total inlet pressure.
PC	λ	Horsepower in coefficient form.
PR	P/p	Ratio of total pressure at inlet to static pressure at exit for a blade row.
PRA	$(P/p)_A$	Approximate total to static pressure ratio across a blade row.
PRC	$(P/p)_C$	Critical pressure across a blade row.
PRE	P_e/p_4	Ratio of total pressure at exit from diffusor to static pressure ahead of the diffusor.
PREO	P_e/P_o	Reciprocal of the overall turbine pressure ratio.
PROE	P_o/P_e	Overall turbine pressure ratio.
PROR	P_R/P_o	Ratio of total pressure after a rotor blade row to the total pressure at inlet to the turbine.
PROS	P_S/P_o	Ratio of total pressure after a stator blade row to the total pressure at inlet to the turbine.
PRRO	P_R/p	Ratio of the total pressure to the static pressure at exit from a rotor blade row.
PRSO	P_S/p	Ratio of the total pressure to the static pressure at exit from a stator blade row.
R	R	Gas constant;(1545/Molecular weight)
RRATE	$\dot{w}\sqrt{T_o}/P_o$	Refered Flow Rate
RRPM	$N/\sqrt{T_o}$	Refered Speed
T	T/T_o	Nondimensional total temperature after a blade row.

TIS	T/T_{is}	Ratio of the temperature at inlet to the temperature at exit of a blade row for isentropic conditions.
TR	T_R/T_o	Equivalent temperature at inlet to a rotor blade row.
TS	T_S/T_o	Equivalent temperature at inlet to a stator blade row.
UI	$U_{(1,3)}/\sqrt{T_o}$	Perpheral speed at the mean radius and rotor inlet.
UO	$U_{(2,4)}/\sqrt{T_o}$	Perpheral speed at the mean radius and rotor exit.
V	$V/\sqrt{T_o}$	Absolute velocity of flow.
VD	$V_D/\sqrt{T_o}$	Absolute velocity of flow at discharge from the diffusor.
VM	$V_m/\sqrt{T_o}$	Meridional component of the absolute velocity.
VRATIO	$U_{AVG.}/C_o$	Velocity ratio for the turbine.
	C_o	Theoretical velocity for isentropic expansion from stagnation pressure at turbine inlet to static pressure at diffusor discharge.
VU	$V_u/\sqrt{T_o}$	Perpheral component of the absolute velocity.
W	$W/\sqrt{T_o}$	Relative velocity of the flow.
WU	$W_u/\sqrt{T_o}$	Perpheral component of the relative velocity.
Z(R,S)	ζ	Total loss coefficient for a row of blades.
ZE(R,S)	ζ_e	Expansion loss from inlet to the throat of a blade row.

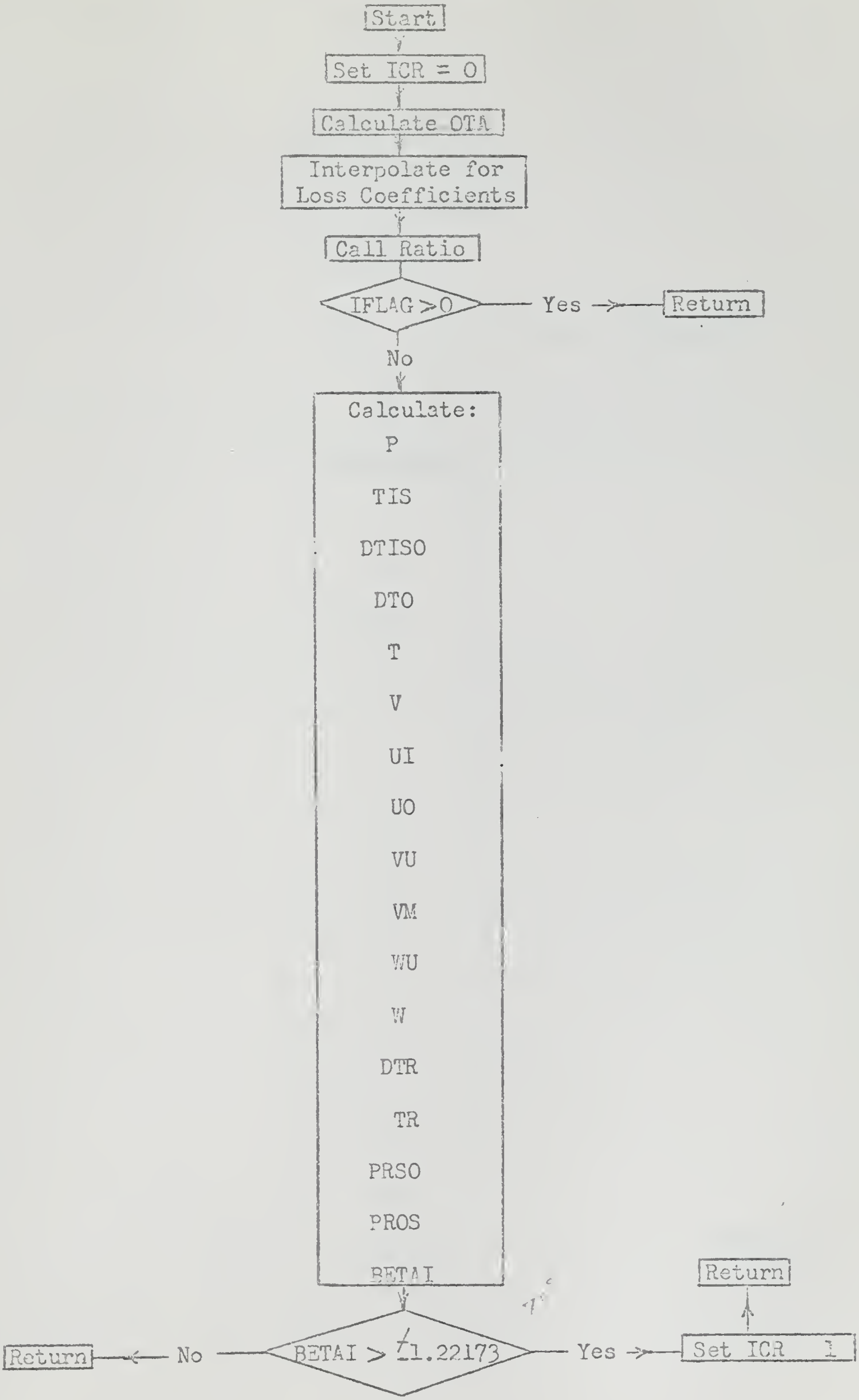
```
      PROGRAM TURBINE
     0DIMENSION AS(20), DMI(20), DMO(20), ALPHAO(20),AR(20), BETAO(20),
     1ZES2(15), ZS2(15), ZER(15,2), ZR(15,2)  ,ZE(2), Z(2)
     0COMMON GAM, RRATE, RRPM, PROS, TR, UO, BETAI, ALPHAI, PROR, TS,
     1T, P, VM, AS, DMI, DMO, ALPHAO, AR, BETAO, IFLAG, ZES2, ZS2,
     2ZER, ZR, R, L, ZE, Z  , OTA, PR  ,ETAT, PC, PROE, VRATIO,ICR,IBR,
     3DAV , ETAD, AD
      GAM = 1.36
      R = 55.16
      ETAD=.70
      AD=92.3
      DAV=13.0
     0READ INPUT TAPE 3, 1, (AS(I),I=1,2), (DMI(I),I=1,2),
     1(DMO(I),I=1,2), (AR(I),I=1,2), (ZES2(I),I=1,15),
     2(ZS2(I),I=1,15),((ZER(I,L),I=1,15),L=1,2),((ZR(I,L),I=1,15),L=1,2)
      READ INPUT TAPE 3, 654, (ALPHAO(I),I=1,2), (BETAO(I),I=1,2)
    1 FORMAT (16F5.0)
  654 FORMAT (4F8.0)
    20FORMAT (5H1RRPM,6X,5HRRATE,4X,4HETAT,4X,2HPC,6X,4HPROE,6X,
     16HVRATIO)
      DO 400 J = 240,540,10
      RRPM=J
      WRITE OUTPUT TAPE 4,2
      DO 300 K = 20,50
      B = K
      RRATE = B/10.
      TS=1.
      PROR=1.
      ZE(1) = .2050
      Z(1) = .2475
      ALPHAI = -.74175
      DO 200 L=1,2
      CALL STATOR
      IF(ICR) 18,18,300
   18 IF(IFLAG) 20,20,900
   20 CALL ROTOR
      IF(IBR)19,19,300
   19 IF(IFLAG)200,200,800
  200 CONTINUE
      CALL DIFFU
      WRITE OUTPUT TAPE 4,3, RRPM,RRATE,ETAT, PC, PROE, VRATIO
    3 FORMAT (F6.1, F9.2, F8.3, F7.4, F9.3, F11.4)
  300 CONTINUE
  900 WRITE OUTPUT TAPE 4,10,L
   10 FORMAT (31H FLOW CHOKED IN STATOR PASS NO.I2)
      GO TO 400
  800 WRITE OUTPUT TAPE 4,11,L
   11 FORMAT (30H FLOW CHOKED IN ROTOR PASS NO.I2)
  400 CONTINUE
      END FILE 4
      END
      FUNCTION EXP3 (GAM)
      EXP3 = (GAM -1.) / GAM
      RETURN
      END
      FUNCTION EXP4 (GAM)
      EXP4 = GAM / (GAM-1.)
      RETURN
      END
      FUNCTION C1 (R)
      C1 = SQRTF (R / 32.174)
      RETURN
      END
      FUNCTION C2 (R,GAM)
      C2 = SQRTF (64.348 * R * GAM / (GAM - 1.))
      RETURN
      END
      FUNCTION C3 (R,GAM)
      C3 = 1. / (64.348 * R * GAM /(GAM-1.)) * 1.E4
      RETURN
      END
```

MAIN PROGRAM

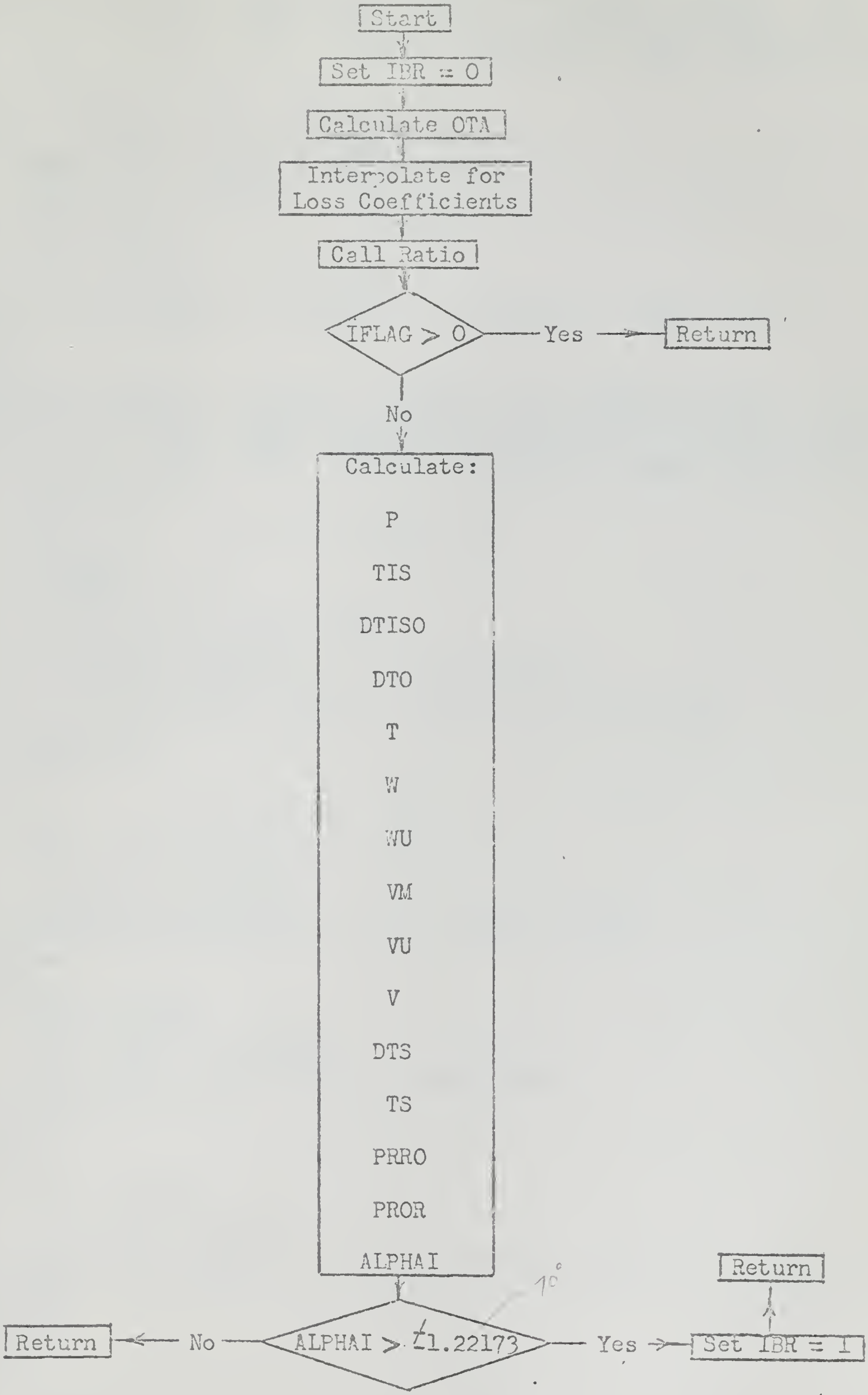


```
      SUBROUTINE STATOR
     ODIMENSION AS(20), DMI(20), DMO(20), ALPHAO(20),AR(20), BETAO(20),
     1ZES2(15), ZS2(15), ZER(15,2), ZR(15,2)   ,ZE(2), Z(2)
     OCOMMON GAM, RRATE, RRPM, PROS, TR, UO, BETAI, ALPHAI, PROR, TS,
     1T, P, VM, AS, DMI, DMO, ALPHAO, AR, BETAO, IFLAG, ZES2, ZS2,
     2ZER, ZR, R, L, ZE, Z   , OTA, PR   ,ETAT, PC, PROE, VRATIO,ICR,IBR,
     3DAV  , ETAD, AD
      ICR = 0
      OTA =RRATE / PROR * C1(R) / AS(L) * SQRTF (TS)
      B1 = (1.22173 - ALPHAI) / .17453 + 1.
      JB = B1
      BB = JB
      DIFF = B1 - BB
      ZE(2) = (ZES2(JB + 1) - ZES2(JB)) * DIFF + ZES2(JB)
      Z(2) = (ZS2(JB + 1) - ZS2(JB)) * DIFF + ZS2(JB)
      CALL RATIO
      IF (IFLAG) 30, 30, 31
   30 P = PROR / PR
      TIS = PR ** EXP3(GAM)
      DTIS = (TIS - 1.) / TIS
      DTISO = DTIS * TS
      DTO = DTISO * (1. - Z(L))
      T = TS - DTO
      V =C2(R,GAM)*SQRTF (DTO)
      UI = .0043633 * RRPM * DMI(L)
      UO = .0043633 * RRPM * DMO(L)
      VU = V * SINF(ALPHAO(L))
      VM = V * COSF(ALPHAO(L))
      WU = VU - UI
      W = SQRTF (VM * VM + WU *WU)
      DTR = C3 (R,GAM)*(W*W+UO*UO-UI*UI) *1.E-4
      TR = T + DTR
      PRSO = (1. + DTR / T) ** EXP4(GAM)
      PROS = PRSO * P
      BETAI = ATANF (WU / VM)
      IF (1.22173 -ABSF(BETAI))321,31,31
  321 ICR = 1
   31 RETURN
      END
      SUBROUTINE ROTOR
     ODIMENSION AS(20), DMI(20), DMO(20), ALPHAO(20),AR(20), BETAO(20),
     1ZES2(15), ZS2(15), ZER(15,2), ZR(15,2)   ,ZE(2), Z(2)
     OCOMMON GAM, RRATE, RRPM, PROS, TR, UO, BETAI, ALPHAI, PROR, TS,
     1T, P, VM, AS, DMI, DMO, ALPHAO, AR, BETAO, IFLAG, ZES2, ZS2,
     2ZER, ZR, R, L, ZE, Z   , OTA, PR   ,ETAT, PC, PROE, VRATIO,ICR,IBR,
     3DAV  , ETAD, AD
      IBR = 0
      OTA = RRATE / PROS * C1(R) / AR(L) * SQRTF (TR)
      B1 = ( 1.22173 - BETAI) / .17453 + 1.
      JB = B1
      BB = JB
      DIFF = B1 - BB
      ZE (L) =  (ZER((JB + 1),L) - ZER(JB,L)) * DIFF + ZER(JB,L)
      Z( L) = ( ZR((JB + 1),L) - ZR(JB,L)) * DIFF + ZR(JB,L)
      CALL RATIO
      IF (IFLAG) 40, 40,41
   40 P = PROS / PR
      TIS = PR** EXP 3(GAM)
      DTIS = (TIS - 1.) / TIS
      DTISO = DTIS * TR
      DTO = DTISO * (1. - Z(L))
      T = TR - DTO
      W = C2(R,GAM)*SQRTF (DTO)
      WU = W * SINF (BETAO(L))
      VM = W * COSF (BETAO(L))
      VU = WU + UO
      V = SQRTF (VM * VM + VU * VU)
      DTS = C3(R,GAM) * V*V*1.E-4
      TS = T + DTS
      PRRO = (1. + DTS /T) ** EXP4(GAM)
      PROR = PRRO * P
      ALPHAI = ATANF (VU / VM)
      IF (1.22173 - ABSF(ALPHAI))322,41,41
  322 IBR = 1
   41 RETURN
      END
```

SUBROUTINE STATOR

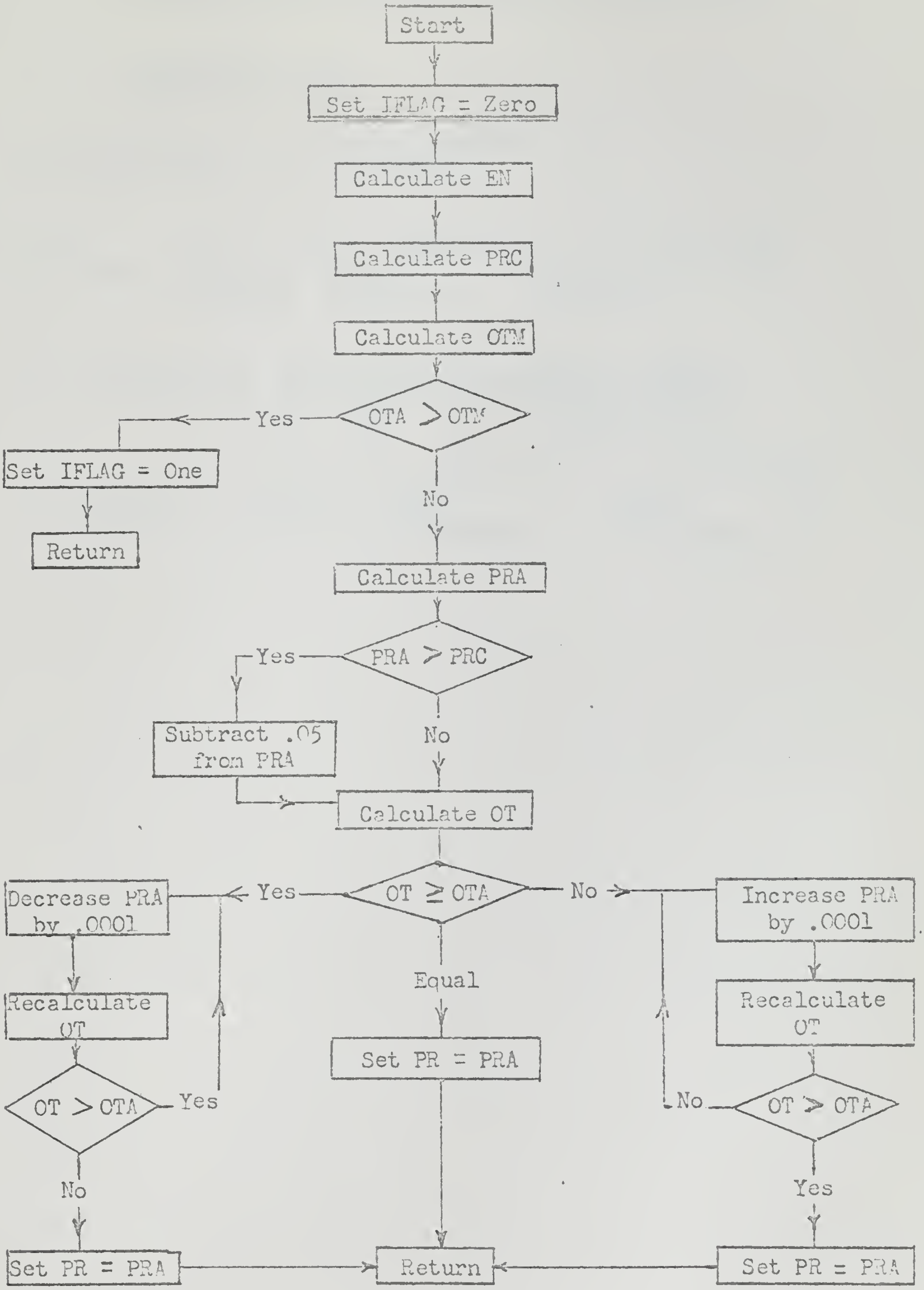


SUBROUTINE ROTOR



```
      SUBROUTINE DIFFU
     0DIMENSION AS(20), DMI(20), DMO(20), ALPHAO(20),AR(20), BETAO(20),
     1ZES2(15), ZS2(15), ZER(15,2), ZR(15,2)  ,ZE(2), Z(2)
     0COMMON GAM, RRATE, RRPM, PROS, TR, UO, BETAI, ALPHAI, PROR, TS,
     1T, P, VM, AS, DMI, DMO, ALPHAO, AR, BETAO, IFLAG, ZES2, ZS2,
     2ZER, ZR, R, L, ZE, Z  , OTA, PR  ,ETAT, PC, PROE, VRATIO,ICR,IBR,
     3DAV , ETAD, AD
      ETADA = ETAD * COSF (ALPHAI) **2.
      DTW = 1. - TS
      CP = R / 778.17 * GAM / (GAM - 1.)
      PC = RRATE * CP * DTW * 1.055
      VD = RRATE * R / AD * T / P
      DTD = C3(R,GAM) * ETADA * (VM * VM - VD * VD) *1.E-4
      PRE = (1. + DTD / T) ** EXP4(GAM)
      PREO = PRE * P
      PROE = 1. / PREO
      DTT = 1. - PREO ** EXP3(GAM)
      ETAT = DTW / DTT
      VRATIO = .0043633 / C2(R,GAM) * RRPM*DAV / SQRTF (DTT)
      RETURN
      END
      SUBROUTINE RATIO
     0DIMENSION AS(20), DMI(20), DMO(20), ALPHAO(20),AR(20), BETAO(20),
     1ZES2(15), ZS2(15), ZER(15,2), ZR(15,2)  ,ZE(2), Z(2)
     0COMMON GAM, RRATE, RRPM, PROS, TR, UO, BETAI, ALPHAI, PROR, TS,
     1T, P, VM, AS, DMI, DMO, ALPHAO, AR, BETAO, IFLAG, ZES2, ZS2,
     2ZER, ZR, R, L, ZE, Z  , OTA, PR  ,ETAT, PC, PROE, VRATIO,ICR,IBR,
     3DAV , ETAD, AD
      IFLAG = 0
      EN = GAM / (1. + ZE(L) * (GAM - 1.))
      EXP1 = 2./EN
      EXP2 = (EN+1.) /EN
      EXP5 = EN/(EN-1.)
      PRC = ((EN + 1.) /2.)** EXP5
      DUNM = 1. / (PRC**EXP1)
      DUGM = 1./(PRC**EXP2)
      OTM = SQRTF (2.*GAM/(GAM-1.)*(DUNM-DUGM))
      IF (OTA-OTM)60,61,61
   60 A = 1. - 3.*(GAM - 1.)/GAM* 1./(EN-1.) * OTA **2.
      IF(A) 52,53,51
   51 A = SQRTF(A)
      GO TO 53
   52 A = 0.
   53 PRA = 1./(1. - EN/3. * (1. -A))
      IF (PRA - PRC) 62,63,63
   63 PRA = PRA - .05
   62 DUN = 1./(PRA ** EXP1)
      DUG = 1./(PRA ** EXP2)
      OT = SQRTF (2.*GAM /(GAM - 1.) * (DUN - DUG))
      IF (OT - OTA)64,65,68
   65 PR = PRA
      RETURN
   64 DO 66 I = 1,500
      PRA = PRA + .0001
      DUN = 1. / (PRA ** EXP1)
      DUG = 1. / (PRA ** EXP2)
      OT = SQRTF (2. *GAM/(GAM-1.) *(DUN-DUG))
      IF (OT-OTA)66,65,67
   66 CONTINUE
   67 PR = PRA
      RETURN
   68 DO 69 I = 1,500
      PRA = PRA - .0001
      DUN = 1. /(PRA**EXP 1)
      DUG = 1./(PRA ** EXP2)
      OT = SQRTF (2. * GAM / (GAM-1.) * (DUN - DUG))
      IF (OT-OTA) 70,65,69
   69 CONTINUE
   70 PR = PRA
      RETURN
   61 IFLAG = 1
      END
      END
```

SUBROUTINE RATIO



EQUATIONS FOR CALCULATIONS MADE IN SUBROUTINE RATIO

(1) $$n = \frac{\gamma}{\eta_e(\gamma - 1.) + 1.}$$

(2) $$(P/p)_{critical} = \left[(n + 1.)/2\right]^{n/(n - 1.)}$$

(3) $$\Phi_{max} = \sqrt{\frac{2\gamma}{\gamma - 1.}\left[\left(\frac{1.}{P/p}\right)_{crit.}^{2/n} - \left(\frac{1.}{P/p}\right)_{crit.}^{(n + 1.)/n}\right]}$$

(4) $$(P/p)_{Approx.} = \frac{1.}{\left\{1. - \frac{n}{3}\left[1. - \sqrt{1. - \frac{3(\gamma - 1.)\Phi^2}{\gamma(n - 1.)}}\right]\right\}}$$

(5) $$\Phi_{Approx.} = \sqrt{\frac{2\gamma}{\gamma - 1.}\left[\left(\frac{1.}{P/p}\right)_{Approx.}^{2/n} - \left(\frac{1.}{P/p}\right)_{Approx.}^{(n + 1.)/n}\right]}$$

APPENDIX IV

Sample Calculations

SAMPLE PERFORMANCE CALCULATIONS USING VALUES

OF THE OPERATING PARAMETERS WHICH GIVE THE

MAXIMUM EFFICIENCY FOR THE DESIGN REFERRED SPEED

$R = 55.16$ ft/ ^{o}R ; $T_o = 1200\ ^{o}F = 1660\ ^{o}R$

$\gamma = 1.36$; $N_o = 18{,}000$ rpm

$\frac{w\sqrt{T_o}}{P_o} = 3.9 \quad \frac{lb_m \sqrt{^{o}R}}{sec\ psia}$ Rotor Tip Clearances = .005

$\frac{N}{\sqrt{T_o}} = 441.8 \quad \frac{rpm}{\sqrt{^{o}R}}$

$$m_1 = \frac{\gamma - 1}{\gamma} = \frac{1.36 - 1.}{1.36} = .26471$$

$$m_2 = \frac{\gamma}{\gamma - 1} = \frac{1.36}{1.36 - 1.} = 3.77778$$

$$C_1 = \sqrt{\frac{R}{g_c}} = \sqrt{\frac{55.16}{32.174}} = 1.30936$$

$$C_2 = \sqrt{\frac{2\gamma gR}{\gamma - 1}} = \sqrt{\frac{2 \times 1.36 \times 32.174 \times 55.16}{1.36 - 1.}} = 115.80$$

$$C_3 = \frac{1 \times 10^4}{2\gamma gR/(\gamma - 1)} = \frac{1. \times 10^4}{2 \times 32.174 \times 55.16 \times 1.36(1.36 - 1)} = .74577$$

$$\frac{\pi}{720} = .0043633$$

Cross-sectional Area of Diffusor - 92.3 sq. in.

Average mean Diameter of Blades - 13.0 in.

****

NOZZLE

$\zeta_e = .0765^{*}$; $\zeta_N = .2475$ loss coefficients for Nozzle.

$$\Phi_N = \frac{w\sqrt{T_o}}{P_o}\ \frac{\sqrt{R/g}}{A_{e1}}\ \frac{\sqrt{T_o/T_o}}{P_o/P_o} = \frac{3.9 \times 1.30936 \times \sqrt{1}}{9.91 \qquad 1} = .51529$$

$$\frac{Po}{p1} = 1.22002$$

*later corrected to .2050

$$\frac{p1}{P_o} = \frac{1.}{1.22002} = .81966$$

$$\frac{T_o}{T_{1is}} = \left(\frac{P_o}{p_1}\right)^{m1} = (1.22002)^{.26471} = 1.05405$$

$$\frac{\Delta T_{isN}}{T_o} = \frac{T_o}{T_o}\left[\frac{(T_o/T_{1is}) - 1}{(T_o/T_{1is})}\right] = \frac{1.05405 - 1.}{1.05405} = .05128$$

$$\frac{\Delta T_N}{T_o} = \frac{\Delta T_{isN}}{T_o}(1. - \zeta_N) = .05128\ (1. - .2475) = .03859$$

$$\frac{T_1}{T_o} = 1. - \frac{\Delta T_N}{T_o} = 1. - .03859 = .96141$$

$$\frac{V_1}{\sqrt{T_o}} = C_2\sqrt{\frac{\Delta T_N}{T_o}} = 115.8\sqrt{.03859} = 22.74684$$

$$\frac{U_1}{\sqrt{T_o}} = .0043633\ \frac{N}{\sqrt{T_o}}\ D_1 = .0043633 \times 441.8 \times 12.8 = 24.67464$$

$$\frac{U_2}{\sqrt{T_o}} = .0043633\ \frac{N}{\sqrt{T_o}}\ D_2 = .0043633 \times 441.8 \times 12.9 = 24.86741$$

$$\frac{V_{u1}}{\sqrt{T_o}} = \frac{V_1}{\sqrt{T_o}}\sin\alpha_1 = 22.74684 \times \sin 64.8^o = 20.76725$$

$$\frac{V_{m1}}{\sqrt{T_o}} = \frac{V_1}{\sqrt{T_o}}\cos\alpha_1 = 22.74684 \times \cos 64.8^o = 9.68500$$

$$\frac{W_{u1}}{\sqrt{T_o}} = \frac{V_{u1}}{\sqrt{T_o}} - \frac{U_1}{\sqrt{T_o}} = 20.76725 - 24.67464 = -4.09261$$

$$\frac{W_1}{\sqrt{T_o}} = \sqrt{\frac{V_{m1}}{T_o}^2 + \frac{W_{u1}}{T_o}^2} = \sqrt{(9.68500)^2 + (-4.09261)^2} = 10.51421$$

$$\frac{\Delta T_{R1}}{T_o} = C_3\left[\frac{W_1}{T_o}^2 + \frac{U_2}{T_o}^2 - \frac{U_1}{T_o}^2\right] \times 10^{-4}$$

$$= .74577\left[(10.51421)^2 + (24.86741)^2 - (24.67464)^2\right] = .00896$$

$$\frac{T_{R1}}{T_o} = \frac{T_1}{T_o} + \frac{\Delta T_{R1}}{T_o} = .96141 + .00896 = .97037$$

$$\frac{P_{R1}}{p_1} = \left[1 + \frac{\Delta T_{R1}/T_o}{T_1/T_o}\right]^{m2} = \left[1. + \frac{.00896}{.96141}\right]^{3.77778} = 1.03565$$

$$\frac{P_{R1}}{P_o} = \left(\frac{P_{R1}}{p_1}\right)\left(\frac{p_1}{P_o}\right) = 1.03565 \times .81966 = .84888$$

$$\beta_1 = \tan^{-1}\left[\frac{W_{u1}/\sqrt{T_o}}{V_{m1}/\sqrt{T_o}}\right] = \tan^{-1}\left[\frac{-4.09261}{9.68500}\right] = -.39981 = -22.9^o$$

ROTOR I

$\zeta_e = .07956 \qquad \zeta_{R1} = .17729$ from loss curves for Rotor I

$$\Phi_{R1} = \frac{w\sqrt{T_o}}{P_o}\frac{\sqrt{R/g}}{A_{e2}}\frac{\sqrt{T_{R1}/T_o}}{P_{R1}/P_o} = \frac{3.9 \times 1.30936 \times \sqrt{.97037}}{11.18 \qquad .84888} = .53003$$

$$\frac{P_{R1}}{p_2} = 1.24332$$

$$\frac{p_2}{P_o} = \frac{P_{R1}/P_o}{P_{R1}/p_2} = \frac{.84888}{1.24332} = .68275$$

$$\frac{T_{R1}}{T_{2is}} = \left(\frac{P_{R1}}{p_2}\right)^{m1} = (1.24332)^{.26471} = 1.05934$$

$$\frac{\Delta T_{is2}}{T_o} = \frac{T_{R1}}{T_o} - \frac{T_{2is}}{T_o} = \frac{T_{R1}}{T_o}\left[\frac{(T_{R1}/T_{2is}) - 1}{T_{R1}/T_{2is}}\right]$$

$$= .97037 \times \frac{(1.05934 - 1.)}{1.05934} = .05436$$

$$\frac{\Delta T_2}{T_o} = \frac{\Delta T_{is2}}{T_o}(1. - \zeta_{R1}) = .05436(1. - .17729) = .04472$$

$$\frac{T_2}{T_o} = \frac{T_{R1}}{T_o} - \frac{\Delta T_2}{T_o} = .97037 - .04472 = .92565$$

$$\frac{W_2}{\sqrt{T_o}} = C_2\sqrt{\frac{\Delta T_2}{T_o}} = 115.8\sqrt{.04472} = 24.48824$$

$$\frac{W_{u2}}{\sqrt{T_o}} = \frac{W_2}{\sqrt{T_o}}\sin\beta_2 = 24.48824 \sin(-64.9^\circ) = -22.17580$$

$$\frac{V_{m2}}{\sqrt{T_o}} = \frac{W_2}{\sqrt{T_o}}\cos\beta_2 = 24.48824 \cos(-64.9^\circ) = 10.38787$$

$$\frac{V_{u2}}{\sqrt{T_o}} = \frac{W_{u2}}{\sqrt{T_o}} + \frac{U_2}{\sqrt{T_o}} = -22.17580 + 24.86741 = 2.69161$$

$$\frac{V_2}{\sqrt{T_o}} = \sqrt{\frac{V_{m2}}{T_o}^2 + \frac{V_{u2}}{T_o}^2} = \sqrt{(10.38787)^2 + (2.69161)^2} = 10.73092$$

$$\frac{\Delta T_{e2}}{T_o} = C_3\,\frac{V_2}{T_o}^2\,10^{-4} = .74577 \times (10.73092)^2 \times 10^{-4} = .00859$$

$$\frac{T_{s2}}{T_o} = \frac{T_2}{T_o} + \frac{\Delta T_{e2}}{T_o} = .92565 + .00859 = .93424$$

$$\frac{P_2}{p_2} = \left[1. + \frac{T_{e2}/T_o}{T_2/T_o}\right]^{m2} = \left[1. + \frac{.00859}{.92565}\right]^{3.77778} = 1.03550$$

$$\frac{P_2}{P_o} = \left(\frac{p_2}{P_o}\right)\left(\frac{P_2}{p_2}\right) = .68275 \times 1.03550 = .70699$$

$$\alpha_2 = \tan^{-1}\left[\frac{V_{u2}/\sqrt{T_o}}{V_{m2}/\sqrt{T_o}}\right] = \tan^{-1}\left[\frac{2.69161}{10.38787}\right] = .25353 = 22.5^\circ$$

STATOR

$\zeta_e = .08698 \quad \zeta_s = .13980$ from loss curves for Stator.

$$\Phi_S = \frac{w\sqrt{T_o}}{P_o}\,\frac{\sqrt{R/g}}{A_{e3}}\,\frac{\sqrt{T_{S2}/T_o}}{P_2/P_o} = \frac{3.9 \times 1.30936 \times \sqrt{.93424}}{11.54 \quad .70699} = .60497$$

$$\frac{P_2}{P_3} = 1.43770$$

$$\frac{p_3}{P_o} = \frac{P_2/P_o}{P_2/p_3} = \frac{.70699}{1.43770} = .49175$$

$$\frac{T_{S2}}{T_{3is}} = \left(\frac{P_2}{p_3}\right)^{m1} = (1.43770)^{.26471} = 1.10087$$

$$\frac{\Delta T_{is3}}{T_o} = \frac{T_{S2}}{T_o}\left[\frac{(T_{S2}/T_{3is}) - 1.}{T_{S2}/T_{3is}}\right] = .93424\left[\frac{1.10087 - 1.}{1.10087}\right] = .08560$$

$$\frac{\Delta T_3}{T_o} = \frac{T_{is3}}{T_o}(1. - \zeta_S) = .08560\,(1. - .13980) = .07363$$

$$\frac{T_3}{T_o} = \frac{T_{S2}}{T_o} - \frac{\Delta T_3}{T_o} = .93424 - .07363 = .86060$$

$$\frac{V_3}{T_o} = C_2\sqrt{\frac{\Delta T_3}{T_o}} = 115.80\sqrt{.07363} = 31.42218$$

$$\frac{U_3}{\sqrt{T_o}} = .0043033\,\frac{N}{\sqrt{T_o}}\,D_3 = .0043633 \times 441.8 \times 13.1 = 25.25295$$

$$\frac{U_4}{\sqrt{T_o}} = .0043633\,\frac{N}{\sqrt{T_o}}\,D_4 = .0043633 \times 441.8 \times 13.2 = 25.44572$$

$$\frac{V_{u3}}{\sqrt{T_o}} = \frac{V_3}{\sqrt{T_o}}\sin\alpha_3 = 31.42218 \sin 69^\circ = 29.33517$$

$$\frac{V_{m3}}{\sqrt{T_o}} = \frac{V_3}{\sqrt{T_o}}\cos\alpha_3 = 31.42218 \cos 69^\circ = 11.26062$$

$$\frac{W_{u3}}{\sqrt{T_o}} = \frac{V_{u3}}{\sqrt{T_o}} - \frac{U_3}{\sqrt{T_o}} = 29.33517 - 25.25295 = 4.08222$$

$$\frac{W_3}{\sqrt{T_o}} = \sqrt{\frac{V_{m3}}{T_o}^2 + \frac{W_{u3}}{T_o}^2} = \sqrt{(11.26062)^2 + (4.08222)^2} = 11.97773$$

$$\frac{\Delta T_{R3}}{T_o} = C_3\left[\frac{W_3}{T_o}^2 + \frac{U_4}{T_o}^2 - \frac{U_3}{T_o}^2\right]10^{-4}$$

$$\frac{\Delta T_{R3}}{T_o} = .74577 \left[(11.97773)^2 + (25.44572)^2 - (25.25295)^2\right] = .01143$$

$$\frac{T_{R3}}{T_o} = \frac{T_3}{T_o} + \frac{\Delta T_{R3}}{T_o} = .86060 + .01143 = .87203$$

$$\frac{p_{R3}}{p_3} = \left[1. + \frac{\Delta T_{R3}/T_o}{T_3/T_o}\right]^{m2} = \left[1. + \frac{.01143}{.86060}\right]^{3.77778} = 1.05110$$

$$\frac{p_{R3}}{p_o} = \left(\frac{p_{R3}}{p_3}\right)\left(\frac{p_3}{p_o}\right) = 1.05110 \times .49175 = .51688$$

$$\beta_3 = \tan^{-1}\left[\frac{W_{u3}/\sqrt{T_o}}{V_{m3}/\sqrt{T_o}}\right] = \tan^{-1}\left[\frac{4.08222}{11.26062}\right] = .34779 = 19.9^\circ$$

ROTOR II

$\zeta_e = .04648 \quad \zeta_{R_2} = .16194$ from loss curves for Rotor II

$$\Phi_{R2} = \frac{w\sqrt{T_o}}{p_o} \frac{\sqrt{R/g}}{A_{e4}} \sqrt{\frac{T_{R3}/T_o}{p_{R3}/p_o}} = 3.9 \times 1.30936 \times \sqrt{\frac{.87203}{.51688}} = .60775$$

$$\frac{p_{R3}}{p_4} = 1.39286$$

$$\frac{p_4}{p_o} = \frac{p_{R3}/p_o}{p_{R3}/p_4} = \frac{.51688}{1.39286} = .37109$$

$$\frac{T_{R3}}{T_{4is}} = \left(\frac{p_{R3}}{p_4}\right)^{m1} = (1.39286)^{.26471} = 1.09167$$

$$\frac{\Delta T_{is4}}{T_o} = \frac{T_{R3}}{T_o}\left[\frac{(T_{R3}/T_{4is}) - 1.}{T_{R3}/T_{4is}}\right] = .87203\left[\frac{1.09167 - 1.}{1.09167}\right] = .07323$$

$$\frac{\Delta T_4}{T_o} = \frac{\Delta T_{is4}}{T_o}(1. - \zeta_{R2}) = .07323\,(1. - .16194) = .06137$$

$$\frac{T_4}{T_o} = \frac{T_{R3}}{T_o} - \frac{\Delta T_4}{T_o} = .87203 - .06137 = .81066$$

$$\frac{W_4}{\sqrt{T_o}} = C_2\sqrt{\frac{\Delta T_4}{T_o}} = 115.8\sqrt{.06137} = 28.68652$$

$$\frac{W_{u4}}{\sqrt{T_o}} = \frac{W_4}{\sqrt{T_o}}\sin\beta_4 = 28.68652\sin(-65^\circ) = -25.99877$$

$$\frac{V_{m4}}{\sqrt{T_o}} = \frac{W_4}{\sqrt{T_o}}\cos\beta_4 = 28.68652\cos(-65^\circ) = 12.12355$$

$$\frac{V_{u4}}{\sqrt{T_o}} = \frac{W_{u4}}{\sqrt{T_o}} + \frac{U_4}{\sqrt{T_o}} = -25.99877 + 25.44572 = -.55305$$

$$\frac{V_4}{\sqrt{T_o}} = \sqrt{\left(\frac{V_{m4}}{\sqrt{T_o}}\right)^2 + \left(\frac{V_{u4}}{\sqrt{T_o}}\right)^2} = \sqrt{(12.12355)^2 + (-.55305)^2} = 12.13616$$

$$\frac{\Delta T_{e4}}{T_o} = C_3 \frac{V_4^2}{T_o} 10^{-4} = .74577 \times (12.13616)^2 \times 10^{-4} = .01098$$

$$\frac{T_{S4}}{T_o} = \frac{T_4}{T_o} + \frac{\Delta T_{e4}}{T_o} = .81066 + .01098 = .82164$$

$$\frac{P_4}{p_4} = \left[1. + \frac{\Delta T_{e4}/T_o}{T_4/T_o}\right]^{m2} = \left[1. + \frac{.01098}{.81066}\right]^{3.77778} = 1.05216$$

$$\frac{P_4}{P_o} = \left(\frac{p_4}{P_o}\right)\left(\frac{P_4}{p_4}\right) = .37109 \times 1.05216 = .39045$$

$$\alpha_4 = \tan^{-1}\left[\frac{V_{u4}/\sqrt{T_o}}{V_{m4}/\sqrt{T_o}}\right] = \tan^{-1}\left[\frac{-.55305}{12.12355}\right] = -.04559 = 2.6^o$$

DIFFUSOR

$\eta_D = .70$ for Axial Exit

$$\eta_A = \eta_D \cos\alpha_4 = .70 \times \cos 2.6^o = .69855$$

$$\frac{\Delta T_w}{T_o} = 1. - \frac{T_{S4}}{T_o} = 1. - .82164 = .17836$$

$$C_p = \frac{R}{J} \frac{\gamma}{\gamma - 1.} = \frac{55.16}{778.17} \times \frac{1.36}{1.36 - 1.} = .26778$$

$$\lambda_T = \frac{w\sqrt{T_o}}{P_o} C_p \frac{\Delta T_w}{T_o} 1.055 = 3.9 \times .26778 \times .17836 \times 1.055 = .19651$$

$$\frac{V_D}{\sqrt{T_o}} = \frac{w\sqrt{T_o}}{P_o} \frac{R}{A_D} \frac{T_4/T_o}{p_4/P_o} = 3.9 \times \frac{55.16}{92.3} \times \frac{.81066}{.37109} = 5.09145$$

$$\frac{\Delta T_{isD}}{T_o} = C_3 \eta_A \left[\frac{V_{m4}}{T_o}^2 - \frac{V_D}{T_o}^2\right] \times 10^{-4}$$

$$= .74577 \times .69855 \times \left[(12.12355)^2 - (5.09145)^2\right] 10^{-4} = .00631$$

$$\frac{P_e}{p_4} = \left[1. + \frac{T_{isD}/T_o}{T_4/T_o}\right]^{m2} = \left[1. + \frac{.00631}{.81066}\right]^{3.77778} = 1.02971$$

$$\frac{P_e}{P_o} = \left(\frac{P_e}{p_4}\right)\left(\frac{p_4}{P_o}\right) = 1.02971 \times .37109 = .38212$$

$$\frac{P_o}{P_e} = \frac{1.}{P_e/P_o} = \frac{1.}{.38212} = 2.61699$$

$$\frac{\Delta T_{isT}}{T_o} = 1. - (P_e/P_o)^{m1} = 1. - (.38212)^{.26471} = .22482$$

$$\eta_T = \frac{\Delta T_w/T_o}{\Delta T_{isT}/T_o} = \frac{.17836}{.22482} = .793$$

$$\frac{U_{avg.}}{C_o} = \frac{.0043633}{C_2} \frac{N}{\sqrt{T_o}} D_{avg.} \frac{1.}{T_{isT}/T_o}$$

$$= \frac{.0043633}{115.8} \times 441.8 \times 13.0 \times \frac{1.}{.22482} = .4564$$

APPENDIX V

Programs and Computor Results

TABLE VIII

Run	Ref. RRPM	Gamma	R	Clearance	A_N	A_{R1}	A_S	A_{R2}	Remarks
1	441.8	1.36	55.16	.033;.021	9.91	11.18	11.54	15.18	Areas & Clear. from Drawings
2	441.8	1.36	55.16	.015	9.91	10.42	11.54	14.87	
3	441.8	1.36	55.16	.010	9.91	10.22	11.54	14.66	
4	441.8	1.36	55.16	.005	9.91	10.01	11.54	14.45	
5	240 - 540	1.36	55.16	.015	9.91	10.42	11.54	14.87	Δ RRATE = .1
6	240 - 540	1.36	55.16	.015	9.91	10.42	11.54	14.87	Δ RRATE = .01 3.7 to Choke
7	441.8	1.36	55.16	.010	8.28	9.38	11.55	14.20	Blade Row Modifications
8	420.9	1.344	53.9	.010	10.32	10.15	11.72	14.65	
9	420.9	1.344	53.9	.015	10.32	10.37	11.72	14.88	
10	420.9	1.344	53.9	.020	10.32	10.58	11.72	15.10	Measured Areas for k = .020
11	407.4	1.336	53.95	.010	10.32	10.15	11.72	14.65	
12	407.4	1.336	53.95	.015	10.32	10.37	11.72	14.88	
13	407.4	1.336	53.95	.020	10.32	10.58	11.72	15.10	
14	533.4	1.398	53.34	.015	10.32	10.37	11.72	14.88	
15	594.3	1.398	53.34	.015	10.32	10.37	11.72	14.88	

<u>SAMPLES OF INPUT DATA</u>

RUN 1

```
 9.9111.54 12.8 13.1 12.9 13.211.1815.18.1680.1520.1375.1210.1070.0930.0820.0710
.0620.0575.0575.0630.0765.1020.1400.2040.1903.1763.1630.1532.1438.1365.1310.1268
.1275.1310.1396.1574.1840.2190.0926.0810.0710.0615.0540.0485.0460.0460.0540.0720
.0980.1330.1760.2500.3400.0885.0770.0670.0585.0515.0465.0440.0440.0500.0620.0820
.1130.1595.2800.5500.5560.4150.3620.3240.2970.2770.2600.2460.2370.2370.2470.2710
.3100.4000.5400.4000.3030.2640.2405.2215.2060.1930.1840.1800.1800.1890.2130.2540
.3900.5500
 1.13098 1.20428-1.13272-1.13446
```

RUN 5 or 6

```
 9.9111.54 12.8 13.1 12.9 13.210.4214.87.1680.1520.1375.1210.1070.0930.0820.0710
.0620.0575.0575.0630.0765.1020.1400.2040.1903.1763.1630.1532.1438.1365.1310.1268
.1275.1310.1396.1574.1840.2190.0926.0810.0710.0615.0540.0485.0460.0460.0540.0720
.0980.1330.1760.2500.3400.0885.0770.0670.0585.0515.0465.0440.0440.0500.0620.0820
.1130.1595.2800.5500.4203.3165.2827.2535.2299.2145.2029.1941.1908.1972.2141.2381
.2771.3500.5500.3625.2747.2426.2213.2022.1902.1792.1709.1684.1699.1767.2036.2456
.3400.5500
 1.13098 1.20428-1.13272-1.13446
```

RUN 7

```
 8.2811.55 12.8 13.1 12.9 13.2 9.3814.20.1680.1520.1375.1210.1070.0930.0820.0710
.0620.0575.0575.0630.0765.1020.1400.2040.1903.1763.1630.1532.1438.1365.1310.1268
.1275.1310.1396.1574.1840.2190.0926.0810.0710.0615.0540.0485.0460.0460.0540.0720
.0980.1330.1760.2500.3400.0885.0770.0670.0585.0515.0465.0440.0440.0500.0620.0820
.1130.1595.2800.5500.3640.2845.2486.2260.2094.1960.1859.1789.1772.1874.1916.2286
.2676.3300.4500.3270.2507.2230.2049.1876.1764.1656.1594.1580.1616.1703.1993.2333
.3200.5000
 1.13098 1.20428-1.13272-1.13446
```

RUN 10 or 13

```
10.3211.72 12.8 13.1 12.9 13.210.5815.10.1680.1520.1375.1210.1070.0930.0820.0710
.0620.0575.0575.0630.0765.1020.1400.2040.1903.1763.1630.1532.1438.1365.1310.1268
.1275.1310.1396.1574.1840.2190.0926.0810.0710.0615.0540.0485.0460.0460.0540.0720
.0980.1330.1760.2500.3400.0885.0770.0670.0585.0515.0465.0440.0440.0500.0620.0820
.1130.1595.2800.5500.4590.3350.3000.2710.2496.2325.2191.2089.2040.2085.2235.2465
.2865.3600.6000.3942.2977.2615.2379.2190.2034.1915.1819.1780.1733.1870.2135.2525
.3500.5000
 1.13098 1.20428-1.13272-1.13446
```

PROGRAM FOR RUN 1

```
..JOB 1
      PROGRAM TURBINE
     0DIMENSION AS(20), DMI(20), DMO(20), ALPHAO(20),AR(20), BETAO(20),
     1ZES2(15), ZS2(15), ZER(15,2), ZR(15,2)  ,ZE(2), Z(2)
     0COMMON GAM, RRATE, RRPM, PROS, TR, UO, BETAI, ALPHAI, PROR, TS,
     1T, P, VM, AS, DMI, DMO, ALPHAO, AR, BETAO, IFLAG, ZES2, ZS2,
     2ZER, ZR, R, L, ZE, Z  , OTA, PR  ,ETAT, PC, PROE, VRATIO,ICR,IBR,
     3DAV , ETAD, AD
      GAM=1.36
      R=55.16
      ETAD=.70
      AD=92.3
      DAV=13.0
     0READ INPUT TAPE 3, 1, (AS(I),I=1,2), (DMI(I),I=1,2),
     1(DMO(I),I=1,2), (AR(I),I=1,2), (ZES2(I),I=1,15),
     2(ZS2(I),I=1,15),((ZER(I,L),I=1,15),L=1,2),((ZR(I,L),I=1,15),L=1,2)
      READ INPUT TAPE 3, 654, (ALPHAO(I),I=1,2), (BETAO(I),I=1,2)
    1 FORMAT (16F5.0)
  654 FORMAT (4F8.0)
    2 0FORMAT (5H1RRPM,6X,5HRRATE,4X,4HETAT,4X,2HPC,6X,4HPROE,6X,
     16HVRATIO)
      DO 400 J= 4418,4418
      A=J
      RRPM=A/10.
      WRITE OUTPUT TAPE 4,2
      DO 300 K = 200,500
      B = K
      RRATE = B/100.
      TS=1.
      PROR=1.
      ZE(1) = .2050
      Z(1) = .2475
      ALPHAI = -.74175
      DO 200 L=1,2
      CALL STATOR
      IF(ICR) 18,18,300
   18 IF(IFLAG) 20,20,900
   20 CALL ROTOR
      IF(IBR)19,19,300
   19 IF(IFLAG)200,200,800
  200 CONTINUE
      CALL DIFFU
      WRITE OUTPUT TAPE 4,3, RRPM,RRATE,ETAT, PC, PROE, VRATIO
    3 FORMAT (F6.1, F9.2, F8.3, F7.4, F9.3, F11.4)
  300 CONTINUE
  900 WRITE OUTPUT TAPE 4,10,L
   10 FORMAT (31H FLOW CHOKED IN STATOR PASS NO.I2)
      GO TO 400
  800 WRITE OUTPUT TAPE 4,11,L
   11 FORMAT (30H FLOW CHOKED IN ROTOR PASS NO.I2)
  400 CONTINUE
      END FILE 4
      END
      FUNCTION EXP3 (GAM)
      EXP3 = (GAM -1.) / GAM
      RETURN
      END
      FUNCTION EXP4 (GAM)
      EXP4 = GAM / (GAM-1.)
      RETURN
      END
      FUNCTION C1 (R)
      C1 = SQRTF (R / 32.174)
      RETURN
      END
      FUNCTION C2 (R,GAM)
      C2 = SQRTF (64.348 * R * GAM / (GAM - 1.))
      RETURN
      END
      FUNCTION C3 (R,GAM)
      C3 = 1. / (64.348 * R * GAM /(GAM-1.)) * 1.E4
      RETURN
      END
```

```
      SUBROUTINE STATOR
     ODIMENSION AS(20), DMI(20), DMO(20), ALPHAO(20),AR(20), BETAO(20),
     1ZES2(15), ZS2(15), ZER(15,2), ZR(15,2)   ,ZE(2), Z(2)
     OCOMMON GAM, RRATE, RRPM, PROS, TR, UO, BETAI, ALPHAI, PROR, TS,
     1T, P, VM, AS, DMI, DMO, ALPHAO, AR, BETAO, IFLAG, ZES2, ZS2,
     2ZER, ZR, R, L, ZE, Z   , OTA, PR   ,ETAT, PC, PROE, VRATIO,ICR,IBR,
     3DAV  , ETAD, AD
      ICR = 0
      OTA =RRATE / PROR * C1(R) / AS(L) * SQRTF (TS)
      B1 = (1.22173 - ALPHAI) / .17453 + 1.
      JB = B1
      BB = JB
      DIFF = B1 - BB
      ZE(2) = (ZES2(JB + 1) - ZES2(JB)) * DIFF + ZES2(JB)
      Z(2) = (ZS2(JB + 1) - ZS2(JB)) * DIFF + ZS2(JB)
      CALL RATIO
      IF (IFLAG) 30, 30, 31
   30 P = PROR / PR
      TIS = PR ** EXP5(GAM)
      DTIS = (TIS - 1.) / TIS
      DTISO = DTIS * TS
      DTO = DTISO * (1. - Z(L))
      T = TS - DTO
      V =C2(R,GAM)*SQRTF (DTO)
      UI = .0043633 * RRPM * DMI(L)
      UO = .0043633 * RRPM * DMO(L)
      VU = V * SINF(ALPHAO(L))
      VM = V * COSF(ALPHAO(L))
      WU = VU - UI
      W = SQRTF (VM * VM + WU *WU)
      DTR = C3 (R,GAM)*(W*W+U)*UO-UI*UI) *1.E-4
      TR = T + DTR
      PRSO = (1. + DTR / T) ** EXP4(GAM)
      PROS = PRSO * P
      BETAI = ATANF (WU / VM)
      IF (1.22173 -ABSF(BETAI))321,31,31
  321 ICR = 1
   31 RETURN
      END
      SUBROUTINE ROTOR
     ODIMENSION AS(20), DMI(20), DMO(20), ALPHAO(20),AR(20), BETAO(20),
     1ZES2(15), ZS2(15), ZER(15,2), ZR(15,2)   ,ZE(2), Z(2)
     OCOMMON GAM, RRATE, RRPM, PROS, TR, UO, BETAI, ALPHAI, PROR, TS,
     1T, P, VM, AS, DMI, DMO, ALPHAO, AR, BETAO, IFLAG, ZES2, ZS2,
     2ZER, ZR, R, L, ZE, Z   , OTA, PR   ,ETAT, PC, PROE, VRATIO,ICR,IBR,
     3DAV  , ETAD, AD
      IBR = 0
      OTA = RRATE / PROS * C1(R) / AR(L) * SQRTF (TR)
      B1 = ( 1.22173 - BETAI) / .17453 + 1.
      JB = B1
      BB = JB
      DIFF = B1 - BB
      ZE (L) =  (ZER((JB + 1),L) - ZER(JB,L)) * DIFF + ZER(JB,L)
      Z( L) = ( ZR((JB + 1),L) - ZR(JB,L)) * DIFF + ZR(JB,L)
      CALL RATIO
      IF (IFLAG) 40, 40,41
   40 P = PROS / PR
      TIS = PR** EXP 5(GAM)
      DTIS = (TIS - 1.) / TIS
      DTISO = DTIS * TR
      DTO = DTISO * (1. - Z(L))
      T = TR - DTO
      W = C2(R,GAM)*SQRTF (DTO)
      WU = W * SINF (BETAO(L))
      VM = W * COSF (BETAO(L))
      VU = WU + UO
      V = SQRTF (VM * VM + VU * VU)
      DTS = C3(R,GAM) * V*V*1.E-4
      TS = T + DTS
      PRRO = (1. + DTS /T) ** EXP4(GAM)
      PROR = PRRO * P
      ALPHAI = ATANF (VU / VM)
      IF (1.22173 - ABSF(ALPHAI))322,41,41
  322 IBR = 1
   41 RETURN
      END
```

```
      SUBROUTINE DIFFC
     0DIMENSION AS(20), DMI(20), DMO(20), ALPHAO(20),AR(20), BETAO(20),
     1ZES2(15), ZS2(15), ZER(15,2), ZR(15,2)  ,ZE(2), Z(2)
     0COMMON GAM, RRATE, RRPM, PROS, TR, UO, BETAI, ALPHAI, PROR, TS,
     1T, P, VM, AS, DMI, DMO, ALPHAO, AR, BETAO, IFLAG, ZES2, ZS2,
     2ZER, ZR, R, L, ZE, Z  , OTA, PR  ,ETAT, PC, PROF, VRATIO,ICR,IBR,
     3DAV , ETAD, AD
      ETADA = ETAD * COSF (ALPHAI) **2.
      DTW = 1. - TS
      CP = R / 778.17 * GAM / (GAM - 1.)
      PC = RRATE * CP * DTW * 1.055
      VD = RRATE * R / AD * T / P
      DTD = C3(R,GAM) * ETADA * (VM * VM - VD * VD) *1.E-4
      PRE = (1. + DTD / T) ** EXP4(GAM)
      PREO = PRE * P
      PROE = 1. / PRE
      DTT = 1. - PREO ** EXP3(GAM)
      ETAT = DTW / DTT
      VRATIO = .0043633 / C2(R,GAM) * RRPM*DAV / SQRTF (DTT)
      RETURN
      END
      SUBROUTINE RATIO
     0DIMENSION AS(20), DMI(20), DMO(20), ALPHAO(20),AR(20), BETAO(20),
     1ZES2(15), ZS2(15), ZER(15,2), ZR(15,2)  ,ZE(2), Z(2)
     0COMMON GAM, RRATE, RRPM, PROS, TR, UO, BETAI, ALPHAI, PROR, TS,
     1T, P, VM, AS, DMI, DMO, ALPHAO, AR, BETAO, IFLAG, ZES2, ZS2,
     2ZER, ZR, R, L, ZE, Z  , OTA, PR  ,ETAT, PC, PROF, VRATIO,ICR,IBR,
     3DAV , ETAD, AD
      IFLAG = 0
      EN = GAM / (1. + ZE(L) * (GAM - 1.))
      EXP1 = 2./EN
      EXP2 = (EN+1.) /EN
      EXP5 = EN/(EN-1.)
      PRC = ((EN + 1.) /2.)** EXP5
      DUNM = 1. / (PRC**EXP1)
      DUGM = 1./(PRC**EXP2)
      OTM = SQRTF (2.*GAM/(GAM-1.)*(DUNM-DUGM))
      IF (OTA-OTM)60,61,61
   60 A = 1. - 3.*(GAM - 1.)/GAM* 1./(EN-1.) * OTA **2.
      IF(A) 52,53,51
   51 A = SQRTF(A)
      GO TO 53
   52 A = 0.
   53 PRA = 1./(1. - EN/3. * (1. -A))
      IF (PRA - PRC) 62,63,63
   63 PRA = PRA - .05
   62 DUN = 1./(PRA ** EXP1)
      DUG = 1./(PRA ** EXP2)
      OT = SQRTF (2.*GAM /(GAM - 1.) * (DUN - DUG))
      IF (OT - OTA)64,65,68
   65 PR = PRA
      RETURN
   64 DO 66 I = 1,500
      PRA = PRA + .0001
      DUN = 1. / (PRA ** EXP1)
      DUG = 1. / (PRA ** EXP2)
      OT = SQRTF (ABSF (2. * GAM / (GAM - 1.) * (DUN - DUG)))
      IF (OT-OTA)66,65,67
   66 CONTINUE
   67 PR = PRA
      RETURN
   68 DO 69 I = 1,500
      PRA = PRA - .0001
      DUN = 1. /(PRA**EXP 1)
      DUG = 1./(PRA ** EXP2)
      OT = SQRTF (ABSF (2. * GAM / (GAM - 1.) * (DUN - DUG)))
      IF (OT-OTA) 70,65,69
   69 CONTINUE
   70 PR = PRA
      RETURN
   61 IFLAG = 1
      END
      END
```

RESULTS OF RUN 1

RRPM	RRATE	ETAT	PC	PRCE	VRATIO
441.8	2.97	.350	.0196	1.298	.8377
441.8	2.98	.362	.0207	1.304	.8309
441.8	2.99	.374	.0218	1.310	.8241
441.8	3.00	.385	.0227	1.316	.8175
441.8	3.01	.396	.0240	1.322	.8110
441.8	3.02	.407	.0251	1.328	.8049
441.8	3.03	.417	.0262	1.334	.7988
441.8	3.04	.428	.0274	1.340	.7929
441.8	3.05	.438	.0285	1.346	.7869
441.8	3.06	.448	.0297	1.352	.7810
441.8	3.07	.458	.0309	1.359	.7752
441.8	3.08	.467	.0321	1.365	.7696
441.8	3.09	.477	.0334	1.372	.7640
441.8	3.10	.486	.0346	1.378	.7585
441.8	3.11	.495	.0359	1.385	.7532
441.8	3.12	.504	.0372	1.391	.7479
441.8	3.13	.512	.0385	1.398	.7427
441.8	3.14	.520	.0398	1.405	.7374
441.8	3.15	.528	.0411	1.413	.7318
441.8	3.16	.535	.0423	1.420	.7266
441.8	3.17	.542	.0437	1.428	.7212
441.8	3.18	.548	.0450	1.436	.7160
441.8	3.19	.555	.0464	1.444	.7109
441.8	3.20	.562	.0477	1.452	.7058
441.8	3.21	.568	.0491	1.460	.7008
441.8	3.22	.574	.0505	1.469	.6959
441.8	3.23	.581	.0520	1.477	.6910
441.8	3.24	.587	.0534	1.486	.6861
441.8	3.25	.592	.0549	1.494	.6813
441.8	3.26	.598	.0563	1.503	.6767
441.8	3.27	.604	.0578	1.512	.6721
441.8	3.28	.609	.0594	1.521	.6675
441.8	3.29	.615	.0609	1.531	.6630
441.8	3.30	.620	.0624	1.540	.6584
441.8	3.31	.625	.0640	1.550	.6538
441.8	3.32	.630	.0656	1.560	.6493
441.8	3.33	.635	.0672	1.570	.6450
441.8	3.34	.639	.0689	1.581	.6406
441.8	3.35	.644	.0705	1.591	.6364
441.8	3.36	.649	.0722	1.601	.6322
441.8	3.37	.653	.0739	1.612	.6279
441.8	3.38	.658	.0756	1.624	.6237
441.8	3.39	.662	.0774	1.635	.6197
441.8	3.40	.667	.0791	1.646	.6156
441.8	3.41	.671	.0809	1.658	.6115
441.8	3.42	.675	.0828	1.670	.6074
441.8	3.43	.679	.0846	1.683	.6033
441.8	3.44	.682	.0865	1.695	.5994
441.8	3.45	.686	.0884	1.708	.5954
441.8	3.46	.690	.0903	1.722	.5914
441.8	3.47	.693	.0923	1.736	.5873
441.8	3.48	.697	.0943	1.750	.5833
441.8	3.49	.700	.0964	1.764	.5793
441.8	3.50	.704	.0985	1.780	.5753
441.8	3.51	.707	.1006	1.795	.5713
441.8	3.52	.710	.1027	1.811	.5673
441.8	3.53	.713	.1049	1.828	.5634
441.8	3.54	.716	.1072	1.845	.5594
441.8	3.55	.719	.1095	1.863	.5554
441.8	3.56	.722	.1118	1.881	.5515
441.8	3.57	.725	.1142	1.900	.5476
441.8	3.58	.727	.1166	1.919	.5437
441.8	3.59	.730	.1191	1.939	.5397
441.8	3.60	.733	.1216	1.960	.5357
441.8	3.61	.735	.1242	1.982	.5318
441.8	3.62	.738	.1269	2.005	.5278

RESULTS OF RUN 1 (cont.)

441.8	3.63	.741	.1297	2.029	.5237
441.8	3.64	.743	.1324	2.053	.5198
441.8	3.65	.745	.1353	2.078	.5158
441.8	3.66	.748	.1383	2.105	.5117
441.8	3.67	.750	.1414	2.135	.5074
441.8	3.68	.752	.1446	2.166	.5032
441.8	3.69	.754	.1480	2.199	.4988
441.8	3.70	.756	.1514	2.234	.4944
441.8	3.71	.758	.1549	2.270	.4900
441.8	3.72	.759	.1587	2.310	.4854
441.8	3.73	.761	.1625	2.352	.4808
441.8	3.74	.762	.1666	2.400	.4759
441.8	3.75	.764	.1708	2.450	.4709
441.8	3.76	.765	.1753	2.505	.4659
441.8	3.77	.765	.1801	2.568	.4604
441.8	3.78	.766	.1852	2.638	.4548
441.8	3.79	.766	.1908	2.719	.4487
441.8	3.80	.766	.1969	2.814	.4422
441.8	3.81	.764	.2038	2.931	.4348
441.8	3.82	.761	.2121	3.089	.4260
441.8	3.83	.754	.2243	3.368	.4128

FLOW CHOKED IN ROTOR PASS NO. 2
TIME, 1 MINUTES AND 5 SECONDS

RESULTS OF RUN 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
441.8	2.83	.276	.0144	1.267	.8760
441.8	2.84	.309	.0153	1.273	.8696
441.8	2.85	.321	.0163	1.278	.8633
441.8	2.86	.334	.0172	1.283	.8571
441.8	2.87	.346	.0181	1.287	.8511
441.8	2.88	.357	.0191	1.292	.8452
441.8	2.89	.369	.0201	1.297	.8388
441.8	2.90	.380	.0211	1.303	.8321
441.8	2.91	.391	.0221	1.309	.8255
441.8	2.92	.402	.0231	1.314	.8191
441.8	2.93	.412	.0242	1.320	.8125
441.8	2.94	.422	.0252	1.326	.8066
441.8	2.95	.432	.0263	1.332	.8006
441.8	2.96	.441	.0274	1.338	.7943
441.8	2.97	.451	.0285	1.345	.7882
441.8	2.98	.460	.0296	1.351	.7821
441.8	2.99	.469	.0308	1.358	.7762
441.8	3.00	.477	.0319	1.364	.7704
441.8	3.01	.486	.0331	1.371	.7649
441.8	3.02	.494	.0342	1.377	.7595
441.8	3.03	.502	.0354	1.384	.7540
441.8	3.04	.510	.0366	1.391	.7486
441.8	3.05	.518	.0378	1.397	.7433
441.8	3.06	.525	.0390	1.404	.7381
441.8	3.07	.533	.0403	1.411	.7330
441.8	3.08	.540	.0415	1.418	.7282
441.8	3.09	.547	.0428	1.425	.7232
441.8	3.10	.554	.0441	1.433	.7183
441.8	3.11	.561	.0454	1.441	.7130
441.8	3.12	.568	.0468	1.449	.7079
441.8	3.13	.574	.0482	1.457	.7028
441.8	3.14	.581	.0495	1.465	.6978
441.8	3.15	.587	.0510	1.474	.6929
441.8	3.16	.593	.0524	1.482	.6881
441.8	3.17	.599	.0538	1.491	.6834
441.8	3.18	.605	.0552	1.499	.6787
441.8	3.19	.611	.0567	1.508	.6741
441.8	3.20	.616	.0582	1.517	.6695
441.8	3.21	.622	.0598	1.526	.6650
441.8	3.22	.628	.0613	1.536	.6605
441.8	3.23	.633	.0629	1.545	.6561
441.8	3.24	.638	.0644	1.555	.6516
441.8	3.25	.643	.0661	1.565	.6472
441.8	3.26	.648	.0676	1.575	.6430
441.8	3.27	.653	.0693	1.585	.6386
441.8	3.28	.658	.0710	1.596	.6343
441.8	3.29	.662	.0727	1.607	.6299
441.8	3.30	.667	.0744	1.618	.6257
441.8	3.31	.671	.0761	1.630	.6215
441.8	3.32	.676	.0779	1.641	.6173
441.8	3.33	.680	.0797	1.653	.6133
441.8	3.34	.685	.0815	1.665	.6092
441.8	3.35	.689	.0833	1.677	.6053
441.8	3.36	.693	.0852	1.689	.6012
441.8	3.37	.697	.0871	1.702	.5973
441.8	3.38	.700	.0890	1.715	.5933
441.8	3.39	.704	.0909	1.728	.5894
441.8	3.40	.708	.0929	1.742	.5854
441.8	3.41	.711	.0949	1.756	.5815
441.8	3.42	.714	.0969	1.771	.5776
441.8	3.43	.718	.0990	1.786	.5737
441.8	3.44	.721	.1010	1.801	.5700
441.8	3.45	.724	.1032	1.816	.5661
441.8	3.46	.728	.1053	1.832	.5623
441.8	3.47	.731	.1076	1.850	.5583
441.8	3.48	.734	.1099	1.867	.5545

441.8	3.49	.737	.1122	1.885	.5505
441.8	3.50	.740	.1146	1.904	.5466
441.8	3.51	.743	.1171	1.924	.5427
441.8	3.52	.745	.1195	1.943	.5389
441.8	3.53	.748	.1221	1.964	.5350
441.8	3.54	.751	.1247	1.985	.5312
441.8	3.55	.754	.1274	2.008	.5272
441.8	3.56	.756	.1301	2.031	.5233
441.8	3.57	.759	.1329	2.055	.5194
441.8	3.58	.761	.1358	2.081	.5154
441.8	3.59	.764	.1388	2.108	.5114
441.8	3.60	.766	.1418	2.135	.5074
441.8	3.61	.769	.1449	2.164	.5033
441.8	3.62	.771	.1482	2.196	.4991
441.8	3.63	.773	.1516	2.230	.4948
441.8	3.64	.775	.1550	2.265	.4906
441.8	3.65	.776	.1586	2.303	.4862
441.8	3.66	.778	.1624	2.344	.4817
441.8	3.67	.780	.1664	2.382	.4770
441.8	3.68	.781	.1706	2.437	.4722
441.8	3.69	.782	.1750	2.491	.4671
441.8	3.70	.783	.1796	2.550	.4619
441.8	3.71	.783	.1846	2.617	.4564
441.8	3.72	.784	.1899	2.693	.4506
441.8	3.73	.783	.1957	2.780	.4444
441.8	3.74	.782	.2021	2.886	.4375
441.8	3.75	.780	.2096	3.021	.4296
441.8	3.76	.776	.2186	3.206	.4201
441.8	3.77	.763	.2337	3.596	.4037

FLOW CHOKED IN ROTOR PASS NO. 2
TIME, 1 MINUTES AND 4 SECONDS

RESULTS OF RUN 3

RRPM	RRATE	ETAT	PC	PROE	VRATIO
441.8	2.73	.218	.0092	1.237	.9253
441.8	2.74	.232	.0100	1.241	.9178
441.8	2.75	.246	.0108	1.246	.9106
441.8	2.76	.260	.0116	1.250	.9035
441.8	2.77	.273	.0124	1.255	.8965
441.8	2.78	.285	.0132	1.259	.8897
441.8	2.79	.298	.0141	1.264	.8833
441.8	2.80	.310	.0149	1.268	.8767
441.8	2.81	.322	.0158	1.273	.8703
441.8	2.82	.333	.0167	1.277	.8640
441.8	2.83	.345	.0175	1.282	.8578
441.8	2.84	.356	.0184	1.287	.8517
441.8	2.85	.367	.0193	1.291	.8459
441.8	2.86	.377	.0202	1.296	.8400
441.8	2.87	.388	.0212	1.301	.8342
441.8	2.88	.398	.0221	1.306	.8251
441.8	2.89	.408	.0231	1.312	.8216
441.8	2.90	.418	.0242	1.318	.8152
441.8	2.91	.428	.0252	1.324	.8090
441.8	2.92	.437	.0262	1.330	.8028
441.8	2.93	.447	.0273	1.336	.7969
441.8	2.94	.456	.0283	1.342	.7910
441.8	2.95	.464	.0294	1.348	.7852
441.8	2.96	.473	.0305	1.354	.7792
441.8	2.97	.482	.0316	1.361	.7733
441.8	2.98	.490	.0328	1.367	.7675
441.8	2.99	.498	.0337	1.374	.7619
441.8	3.00	.506	.0351	1.381	.7564
441.8	3.01	.513	.0362	1.387	.7511
441.8	3.02	.521	.0374	1.394	.7457
441.8	3.03	.528	.0386	1.401	.7406
441.8	3.04	.535	.0398	1.408	.7355
441.8	3.05	.542	.0410	1.415	.7304
441.8	3.06	.549	.0423	1.422	.7254
441.8	3.07	.556	.0435	1.429	.7205
441.8	3.08	.563	.0448	1.437	.7156
441.8	3.09	.570	.0461	1.444	.7108
441.8	3.10	.576	.0475	1.452	.7056
441.8	3.11	.583	.0488	1.461	.7005
441.8	3.12	.589	.0502	1.469	.6955
441.8	3.13	.595	.0517	1.478	.6906
441.8	3.14	.601	.0531	1.486	.6858
441.8	3.15	.607	.0545	1.495	.6810
441.8	3.16	.613	.0560	1.504	.6764
441.8	3.17	.618	.0574	1.513	.6719
441.8	3.18	.624	.0589	1.522	.6674
441.8	3.19	.629	.0604	1.531	.6628
441.8	3.20	.635	.0620	1.540	.6583
441.8	3.21	.640	.0636	1.550	.6539
441.8	3.22	.645	.0651	1.560	.6496
441.8	3.23	.650	.0668	1.570	.6452
441.8	3.24	.655	.0684	1.580	.6409
441.8	3.25	.660	.0701	1.591	.6365
441.8	3.26	.665	.0718	1.601	.6322
441.8	3.27	.670	.0735	1.612	.6280
441.8	3.28	.675	.0753	1.623	.6237
441.8	3.29	.679	.0770	1.635	.6196
441.8	3.30	.684	.0788	1.646	.6155
441.8	3.31	.689	.0807	1.658	.6114
441.8	3.32	.693	.0825	1.670	.6074
441.8	3.33	.697	.0844	1.682	.6035
441.8	3.34	.702	.0863	1.695	.5995
441.8	3.35	.706	.0882	1.707	.5956
441.8	3.36	.710	.0902	1.721	.5916
441.8	3.37	.714	.0922	1.734	.5876
441.8	3.38	.718	.0942	1.748	.5838

441.8	3.39	.721	.0962	1.762	.5799
441.8	3.40	.725	.0983	1.777	.5760
441.8	3.41	.728	.1003	1.792	.5722
441.8	3.42	.732	.1025	1.807	.5684
441.8	3.43	.735	.1047	1.823	.5646
441.8	3.44	.739	.1068	1.838	.5609
441.8	3.45	.742	.1091	1.855	.5573
441.8	3.46	.745	.1114	1.872	.5534
441.8	3.47	.748	.1138	1.891	.5494
441.8	3.48	.751	.1161	1.909	.5456
441.8	3.49	.753	.1186	1.929	.5417
441.8	3.50	.756	.1211	1.949	.5378
441.8	3.51	.759	.1236	1.970	.5338
441.8	3.52	.761	.1263	1.992	.5299
441.8	3.53	.764	.1290	2.015	.5260
441.8	3.54	.766	.1317	2.039	.5220
441.8	3.55	.769	.1346	2.065	.5179
441.8	3.56	.771	.1375	2.091	.5139
441.8	3.57	.773	.1405	2.118	.5099
441.8	3.58	.775	.1435	2.146	.5058
441.8	3.59	.778	.1467	2.177	.5017
441.8	3.60	.780	.1500	2.209	.4975
441.8	3.61	.781	.1534	2.243	.4932
441.8	3.62	.783	.1570	2.280	.4889
441.8	3.63	.785	.1607	2.319	.4844
441.8	3.64	.786	.1645	2.361	.4798
441.8	3.65	.788	.1684	2.406	.4752
441.8	3.66	.789	.1726	2.456	.4704
441.8	3.67	.790	.1771	2.512	.4653
441.8	3.68	.790	.1819	2.574	.4599
441.8	3.69	.791	.1870	2.644	.4543
441.8	3.70	.790	.1924	2.723	.4484
441.8	3.71	.790	.1985	2.819	.4419
441.8	3.72	.788	.2053	2.934	.4347
441.8	3.73	.785	.2131	3.082	.4263
441.8	3.74	.777	.2242	3.350	.4135

FLOW CHOKED IN ROTOR PASS NO. 2
TIME, 1 MINUTES AND 2 SECONDS

RESULTS OF RUN 4

RRPM	RRATE	FEAT	PC	PROF	VRATIO
441.8	2.53	-.020	-.0006	1.166	1.0855
441.8	2.54	.004	.0001	1.170	1.0738
441.8	2.55	.027	.0008	1.174	1.0624
441.8	2.56	[illegible]	.0014	1.178	1.0513
441.8	2.57	.070	.0022	1.182	1.0409
441.8	2.58	.091	.0029	1.186	1.0308
441.8	2.59	.111	.0036	1.190	1.0203
441.8	2.60	.130	.0044	1.194	1.0104
441.8	2.61	.146	.0050	1.198	1.0010
441.8	2.62	.162	.0057	1.202	.9917
441.8	2.63	.178	.0064	1.207	.9827
441.8	2.64	.193	.0071	1.211	.9739
441.8	2.65	.208	.0078	1.215	.9654
441.8	2.66	.222	.0085	1.219	.9570
441.8	2.67	.236	.0093	1.224	.9488
441.8	2.68	.250	.0100	1.228	.9408
441.8	2.69	.263	.0107	1.232	.9330
441.8	2.70	.275	.0115	1.237	.9254
441.8	2.71	.288	.0122	1.241	.9179
441.8	2.72	.300	.0130	1.246	.9106
441.8	2.73	.312	.0138	1.250	.9035
441.8	2.74	.323	.0146	1.255	.8965
441.8	2.75	.334	.0154	1.259	.8897
441.8	2.76	.345	.0162	1.264	.8829
441.8	2.77	.355	.0170	1.268	.8764
441.8	2.78	.365	.0178	1.273	.8702
441.8	2.79	.376	.0186	1.277	.8638
441.8	2.80	.385	.0194	1.282	.8576
441.8	2.81	.395	.0203	1.287	.8516
441.8	2.82	.404	.0211	1.292	.8456
441.8	2.83	.414	.0220	1.296	.8397
441.8	2.84	.423	.0228	1.301	.8340
441.8	2.85	.431	.0237	1.306	.8283
441.8	2.86	.440	.0246	1.311	.8228
441.8	2.87	.449	.0255	1.317	.8167
441.8	2.88	.457	.0265	1.322	.8104
441.8	2.89	.465	.0275	1.328	.8042
441.8	2.90	.473	.0285	1.334	.7981
441.8	2.91	.480	.0295	1.340	.7922
441.8	2.92	.488	.0305	1.347	.7864
441.8	2.93	.495	.0315	1.352	.7803
441.8	2.94	.502	.0325	1.359	.7752
441.8	2.95	.509	.0335	1.365	.7697
441.8	2.96	.516	.0346	1.372	.7639
441.8	2.97	.522	.0357	1.378	.7583
441.8	2.98	.529	.0368	1.385	.7527
441.8	2.99	.535	.0379	1.392	.7473
441.8	3.00	.541	.0390	1.399	.7420
441.8	3.01	.547	.0401	1.406	.7368
441.8	3.02	.553	.0412	1.413	.7318
441.8	3.03	.558	.0424	1.420	.7267
441.8	3.04	.564	.0436	1.428	.7217
441.8	3.05	.570	.0447	1.435	.7168
441.8	3.06	.575	.0459	1.442	.7120
441.8	3.07	.580	.0471	1.450	.7072
441.8	3.08	.586	.0484	1.458	.7024
441.8	3.09	.592	.0498	1.466	.6973
441.8	3.10	.598	.0512	1.474	.6925
441.8	3.11	.604	.0526	1.483	.6376
441.8	3.12	.610	.0540	1.492	.6827
441.8	3.13	.616	.0555	1.501	.6779
441.8	3.14	.621	.0570	1.510	.6732
441.8	3.15	.627	.0585	1.519	.6685
441.8	3.16	.632	.0600	1.528	.6641
441.8	3.17	.638	.0615	1.538	.6596
441.8	3.18	.643	.0630	1.547	.6552

RESULTS OF RUN 4 (cont.)

441.8	3.19	.648	.0646	1.557	.6507
441.8	3.20	.654	.0662	1.567	.6464
441.8	3.21	.659	.0678	1.577	.6422
441.8	3.22	.664	.0695	1.587	.6380
441.8	3.23	.668	.0711	1.598	.6337
441.8	3.24	.673	.0727	1.609	.6294
441.8	3.25	.678	.0746	1.620	.6251
441.8	3.26	.683	.0763	1.631	.6211
441.8	3.27	.687	.0781	1.642	.6169
441.8	3.28	.692	.0800	1.654	.6127
441.8	3.29	.696	.0818	1.666	.6086
441.8	3.30	.701	.0837	1.678	.6045
441.8	3.31	.705	.0856	1.691	.6006
441.8	3.32	.709	.0875	1.704	.5967
441.8	3.33	.714	.0895	1.716	.5929
441.8	3.34	.718	.0915	1.730	.5890
441.8	3.35	.722	.0935	1.744	.5850
441.8	3.36	.725	.0955	1.758	.5811
441.8	3.37	.729	.0976	1.772	.5772
441.8	3.38	.733	.0997	1.787	.5734
441.8	3.39	.736	.1018	1.802	.5696
441.8	3.40	.740	.1039	1.818	.5658
441.8	3.41	.743	.1061	1.834	.5620
441.8	3.42	.747	.1084	1.850	.5583
441.8	3.43	.750	.1106	1.866	.5546
441.8	3.44	.753	.1130	1.884	.5509
441.8	3.45	.756	.1154	1.902	.5471
441.8	3.46	.759	.1178	1.921	.5432
441.8	3.47	.762	.1203	1.942	.5392
441.8	3.48	.765	.1229	1.962	.5353
441.8	3.49	.767	.1255	1.984	.5314
441.8	3.50	.770	.1282	2.006	.5275
441.8	3.51	.773	.1310	2.030	.5235
441.8	3.52	.775	.1338	2.054	.5195
441.8	3.53	.777	.1366	2.080	.5155
441.8	3.54	.780	.1397	2.107	.5114
441.8	3.55	.782	.1427	2.135	.5074
441.8	3.56	.784	.1459	2.165	.5033
441.8	3.57	.786	.1492	2.197	.4990
441.8	3.58	.788	.1524	2.229	.4949
441.8	3.59	.790	.1560	2.265	.4906
441.8	3.60	.792	.1596	2.304	.4861
441.8	3.61	.793	.1633	2.345	.4816
441.8	3.62	.794	.1673	2.389	.4770
441.8	3.63	.796	.1714	2.437	.4722
441.8	3.64	.797	.1757	2.489	.4673
441.8	3.65	.797	.1803	2.548	.4622
441.8	3.66	.798	.1851	2.615	.4568
441.8	3.67	.797	.1905	2.690	.4503
441.8	3.68	.797	.1963	2.778	.4446
441.8	3.69	.795	.2028	2.886	.4376
441.8	3.70	.793	.2102	3.019	.4298
441.8	3.71	.788	.2193	3.208	.4200
441.8	3.72	.772	.2365	3.674	.4009

FLOW CHOKED IN ROTOR PASS NO. 2
TIME, 1 MINUTES AND 2 SECONDS

RESULTS OF RUN 5

RRPM	RRATE	ETAT	PC	PROE	VRATIO
240.0	2.00	.582	.0099	1.122	.6786
240.0	2.10	.632	.0129	1.141	.6339
240.0	2.20	.670	.0162	1.162	.5959
240.0	2.30	.699	.0198	1.184	.5626
240.0	2.40	.720	.0237	1.207	.5330
240.0	2.50	.734	.0280	1.233	.5059
240.0	2.60	.745	.0327	1.262	.4815
240.0	2.70	.753	.0377	1.293	.4585
240.0	2.80	.757	.0433	1.327	.4374
240.0	2.90	.760	.0493	1.366	.4177
240.0	3.00	.760	.0559	1.409	.3989
240.0	3.10	.759	.0632	1.459	.3811
240.0	3.20	.755	.0712	1.516	.3639
240.0	3.30	.749	.0801	1.584	.3471
240.0	3.40	.742	.0901	1.666	.3306
240.0	3.50	.731	.1014	1.769	.3140
240.0	3.60	.719	.1146	1.904	.2969
240.0	3.70	.702	.1306	2.096	.2788
240.0	3.80	.677	.1518	2.422	.2573

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
250.0	2.00	.538	.0090	1.120	.7135
250.0	2.10	.598	.0120	1.139	.6656
250.0	2.20	.644	.0154	1.160	.6238
250.0	2.30	.679	.0192	1.183	.5878
250.0	2.40	.705	.0232	1.207	.5559
250.0	2.50	.724	.0276	1.233	.5274
250.0	2.60	.738	.0324	1.262	.5011
250.0	2.70	.748	.0376	1.294	.4770
250.0	2.80	.755	.0433	1.329	.4547
250.0	2.90	.759	.0496	1.369	.4338
250.0	3.00	.762	.0565	1.413	.4141
250.0	3.10	.762	.0640	1.464	.3953
250.0	3.20	.759	.0723	1.523	.3773
250.0	3.30	.755	.0816	1.593	.3596
250.0	3.40	.748	.0920	1.678	.3423
250.0	3.50	.739	.1039	1.784	.3249
250.0	3.60	.727	.1178	1.926	.3068
250.0	3.70	.711	.1347	2.130	.2875
250.0	3.80	.685	.1576	2.489	.2645

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
260.0	2.00	.486	.0079	1.116	.7513
260.0	2.10	.559	.0110	1.136	.6985
260.0	2.20	.613	.0145	1.158	.6532
260.0	2.30	.655	.0183	1.181	.6139
260.0	2.40	.687	.0225	1.206	.5796
260.0	2.50	.711	.0270	1.232	.5490
260.0	2.60	.729	.0320	1.262	.5213
260.0	2.70	.742	.0374	1.294	.4958
260.0	2.80	.751	.0432	1.330	.4722
260.0	2.90	.758	.0497	1.371	.4501
260.0	3.00	.762	.0568	1.416	.4293
260.0	3.10	.763	.0646	1.468	.4097
260.0	3.20	.763	.0732	1.528	.3908
260.0	3.30	.760	.0829	1.600	.3723
260.0	3.40	.754	.0937	1.688	.3541
260.0	3.50	.746	.1062	1.798	.3358
260.0	3.60	.735	.1207	1.946	.3169
260.0	3.70	.718	.1387	2.163	.2963
260.0	3.80	.691	.1635	2.560	.2713

FLOW CHOKED IN STATOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
270.0	2.00	.426	.0067	1.113	.7928
270.0	2.10	.513	.0099	1.133	.7330
270.0	2.20	.578	.0134	1.155	.6844
270.0	2.30	.627	.0173	1.178	.6413
270.0	2.40	.666	.0216	1.204	.6040
270.0	2.50	.696	.0263	1.231	.5713
270.0	2.60	.718	.0314	1.261	.5418
270.0	2.70	.734	.0369	1.294	.5148
270.0	2.80	.746	.0430	1.331	.4900
270.0	2.90	.755	.0497	1.372	.4667
270.0	3.00	.761	.0570	1.419	.4448
270.0	3.10	.764	.0651	1.472	.4241
270.0	3.20	.765	.0740	1.534	.4043
270.0	3.30	.764	.0840	1.607	.3850
270.0	3.40	.760	.0953	1.697	.3659
270.0	3.50	.752	.1083	1.812	.3467
270.0	3.60	.742	.1236	1.965	.3269
270.0	3.70	.726	.1425	2.194	.3052
270.0	3.80	.697	.1693	2.634	.2781

FLOW CHOKED IN STATOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
280.0	2.10	.460	.0087	1.129	.7703
280.0	2.20	.537	.0123	1.152	.7160
280.0	2.30	.596	.0162	1.176	.6700
280.0	2.40	.641	.0206	1.202	.6295
280.0	2.50	.676	.0255	1.230	.5941
280.0	2.60	.704	.0307	1.260	.5627
280.0	2.70	.724	.0364	1.294	.5342
280.0	2.80	.739	.0426	1.331	.5079
280.0	2.90	.750	.0495	1.373	.4835
280.0	3.00	.758	.0570	1.421	.4605
280.0	3.10	.763	.0654	1.475	.4387
280.0	3.20	.766	.0746	1.538	.4180
280.0	3.30	.766	.0850	1.613	.3977
280.0	3.40	.764	.0967	1.705	.3779
280.0	3.50	.758	.1102	1.824	.3577
280.0	3.60	.748	.1262	1.984	.3368
280.0	3.70	.733	.1461	2.224	.3141
280.0	3.80	.703	.1750	2.710	.2848

FLOW CHOKED IN STATOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
290.0	2.10	.400	.0073	1.125	.8117
290.0	2.20	.491	.0109	1.148	.7498
290.0	2.30	.560	.0150	1.172	.7000
290.0	2.40	.612	.0195	1.199	.6561
290.0	2.50	.654	.0244	1.228	.6180
290.0	2.60	.687	.0298	1.259	.5841
290.0	2.70	.712	.0357	1.293	.5538
290.0	2.80	.730	.0421	1.331	.5263
290.0	2.90	.744	.0491	1.373	.5005
290.0	3.00	.755	.0569	1.422	.4764
290.0	3.10	.762	.0655	1.477	.4535
290.0	3.20	.766	.0750	1.542	.4317
290.0	3.30	.768	.0857	1.619	.4106
290.0	3.40	.767	.0979	1.713	.3898
290.0	3.50	.763	.1119	1.834	.3688
290.0	3.60	.754	.1286	2.001	.3469
290.0	3.70	.739	.1496	2.255	.3228
290.0	3.80	.708	.1807	2.787	.2914

FLOW CHOKED IN STATOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
300.0	2.20	.457	.0095	1.144	.7869
300.0	2.30	.518	.0136	1.169	.7309
300.0	2.40	.581	.0182	1.195	.6844
300.0	2.50	.628	.0232	1.225	.6427
300.0	2.60	.667	.0288	1.257	.6063
300.0	2.70	.697	.0348	1.292	.5741
300.0	2.80	.719	.0414	1.330	.5448
300.0	2.90	.737	.0486	1.373	.5178
300.0	3.00	.750	.0566	1.423	.4923
300.0	3.10	.759	.0654	1.479	.4686
300.0	3.20	.766	.0752	1.545	.4457
300.0	3.30	.769	.0863	1.623	.4236
300.0	3.40	.770	.0989	1.720	.4018
300.0	3.50	.767	.1135	1.845	.3799
300.0	3.60	.760	.1309	2.016	.3571
300.0	3.70	.745	.1530	2.284	.3316
300.0	3.80	.713	.1864	2.871	.2977

FLOW CHOKED IN STATOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
310.0	2.20	.376	.0079	1.139	.8265
310.0	2.30	.471	.0121	1.164	.7642
310.0	2.40	.544	.0167	1.192	.7132
310.0	2.50	.600	.0219	1.221	.6687
310.0	2.60	.644	.0275	1.254	.6296
310.0	2.70	.679	.0338	1.290	.5947
310.0	2.80	.707	.0406	1.329	.5638
310.0	2.90	.727	.0480	1.373	.5352
310.0	3.00	.743	.0561	1.423	.5087
310.0	3.10	.755	.0652	1.480	.4836
310.0	3.20	.764	.0753	1.547	.4598
310.0	3.30	.769	.0867	1.627	.4366
310.0	3.40	.772	.0997	1.726	.4141
310.0	3.50	.771	.1149	1.854	.3911
310.0	3.60	.764	.1329	2.030	.3673
310.0	3.70	.751	.1560	2.310	.3406
310.0	3.80	.716	.1922	2.965	.3037

FLOW CHOKED IN STATOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
320.0	2.30	.418	.0104	1.159	.8009
320.0	2.40	.502	.0151	1.187	.7434
320.0	2.50	.568	.0203	1.217	.6963
320.0	2.60	.619	.0261	1.251	.6535
320.0	2.70	.659	.0325	1.287	.6163
320.0	2.80	.691	.0395	1.328	.5831
320.0	2.90	.716	.0472	1.372	.5530
320.0	3.00	.735	.0555	1.423	.5251
320.0	3.10	.750	.0648	1.481	.4989
320.0	3.20	.761	.0752	1.549	.4740
320.0	3.30	.768	.0869	1.630	.4499
320.0	3.40	.772	.1003	1.731	.4262
320.0	3.50	.773	.1160	1.862	.4025
320.0	3.60	.769	.1348	2.044	.3775
320.0	3.70	.756	.1589	2.335	.3496
320.0	3.80	.719	.1982	3.069	.3093

FLOW CHOKED IN STATOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
330.0	2.30	.357	.0086	1.154	.8387
330.0	2.40	.456	.0134	1.182	.7762
330.0	2.50	.531	.0187	1.213	.7239
330.0	2.60	.590	.0246	1.247	.6789
330.0	2.70	.636	.0311	1.294	.6386
330.0	2.80	.673	.0383	1.325	.6031
330.0	2.90	.703	.0462	1.371	.5712
330.0	3.00	.726	.0548	1.422	.5418
330.0	3.10	.743	.0643	1.481	.5145
330.0	3.20	.757	.0750	1.550	.4884
330.0	3.30	.766	.0870	1.633	.4633
330.0	3.40	.772	.1008	1.736	.4386
330.0	3.50	.775	.1169	1.869	.4138
330.0	3.60	.772	.1365	2.056	.3878
330.0	3.70	.761	.1616	2.359	.3586
330.0	3.80	.721	.2042	3.181	.3147

FLOW CHOKED IN STATOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
340.0	2.40	.403	.0115	1.176	.8123
340.0	2.50	.490	.0169	1.208	.7534
340.0	2.60	.559	.0229	1.242	.7054
340.0	2.70	.611	.0295	1.280	.6619
340.0	2.80	.654	.0368	1.322	.6241
340.0	2.90	.688	.0449	1.369	.5897
340.0	3.00	.715	.0538	1.421	.5588
340.0	3.10	.735	.0636	1.481	.5300
340.0	3.20	.751	.0745	1.551	.5030
340.0	3.30	.763	.0869	1.635	.4766
340.0	3.40	.772	.1010	1.739	.4512
340.0	3.50	.776	.1177	1.876	.4253
340.0	3.60	.776	.1379	2.067	.3983
340.0	3.70	.765	.1642	2.382	.3676
340.0	3.80	.715	.2137	3.428	.3157

FLOW CHOKED IN STATOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
350.0	2.40	.341	.0095	1.171	.8478
350.0	2.50	.443	.0149	1.202	.7857
350.0	2.60	.522	.0210	1.237	.7322
350.0	2.70	.583	.0277	1.275	.6867
350.0	2.80	.631	.0352	1.318	.6455
350.0	2.90	.670	.0435	1.366	.6091
350.0	3.00	.702	.0527	1.420	.5761
350.0	3.10	.726	.0627	1.480	.5460
350.0	3.20	.745	.0739	1.552	.5175
350.0	3.30	.760	.0866	1.637	.4903
350.0	3.40	.770	.1011	1.743	.4636
350.0	3.50	.776	.1182	1.881	.4369
350.0	3.60	.778	.1391	2.077	.4088
350.0	3.70	.769	.1665	2.402	.3768
350.0	3.80	.717	.2196	3.556	.3210

FLOW CHOKED IN STATOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
360.0	2.50	.391	.0127	1.195	.8210
360.0	2.60	.481	.0190	1.232	.7611
360.0	2.70	.551	.0258	1.270	.7121
360.0	2.80	.606	.0334	1.314	.6681
360.0	2.90	.651	.0419	1.362	.6291
360.0	3.00	.687	.0513	1.417	.5940
360.0	3.10	.715	.0616	1.479	.5621
360.0	3.20	.737	.0731	1.551	.5324
360.0	3.30	.754	.0861	1.638	.5039
360.0	3.40	.767	.1011	1.746	.4762
360.0	3.50	.776	.1186	1.886	.4485
360.0	3.60	.779	.1401	2.086	.4194
360.0	3.70	.773	.1686	2.421	.3861

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
370.0	2.50	.331	.0105	1.190	.8543
370.0	2.60	.435	.0167	1.225	.7925
370.0	2.70	.515	.0237	1.265	.7381
370.0	2.80	.579	.0314	1.308	.6922
370.0	2.90	.629	.0401	1.358	.6498
370.0	3.00	.670	.0497	1.414	.6125
370.0	3.10	.702	.0603	1.477	.5787
370.0	3.20	.728	.0721	1.550	.5475
370.0	3.30	.748	.0855	1.639	.5177
370.0	3.40	.764	.1008	1.757	.4891
370.0	3.50	.775	.1189	1.891	.4601
370.0	3.60	.780	.1409	2.093	.4301
370.0	3.70	.777	.1705	2.438	.3954

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
380.0	2.60	.384	.0143	1.217	.8270
380.0	2.70	.476	.0214	1.258	.7662
380.0	2.80	.548	.0292	1.302	.7165
380.0	2.90	.605	.0381	1.352	.6716
380.0	3.00	.651	.0479	1.409	.6318
380.0	3.10	.688	.0588	1.474	.5959
380.0	3.20	.717	.0710	1.549	.5627
380.0	3.30	.741	.0846	1.638	.5318
380.0	3.40	.759	.1004	1.750	.5017
380.0	3.50	.773	.1189	1.894	.4719
380.0	3.60	.780	.1417	2.102	.4406
380.0	3.70	.779	.1722	2.453	.4048

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
390.0	2.60	.325	.0118	1.212	.8583
390.0	2.70	.431	.0189	1.251	.7967
390.0	2.80	.513	.0269	1.296	.7417
390.0	2.90	.578	.0358	1.346	.6947
390.0	3.00	.630	.0459	1.404	.6516
390.0	3.10	.672	.0570	1.470	.6134
390.0	3.20	.705	.0695	1.547	.5785
390.0	3.30	.732	.0835	1.638	.5460
390.0	3.40	.753	.0997	1.751	.5146
390.0	3.50	.770	.1188	1.898	.4836
390.0	3.60	.780	.1422	2.109	.4513
390.0	3.70	.781	.1737	2.470	.4141

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
400.0	2.70	.381	.0162	1.242	.8296
400.0	2.80	.474	.0244	1.289	.7689
400.0	2.90	.548	.0334	1.339	.7185
400.0	3.00	.607	.0436	1.398	.6726
400.0	3.10	.654	.0551	1.465	.6318
400.0	3.20	.692	.0679	1.543	.5949
400.0	3.30	.722	.0823	1.637	.5604
400.0	3.40	.747	.0988	1.750	.5280
400.0	3.50	.766	.1184	1.901	.4955
400.0	3.60	.779	.1424	2.114	.4621
400.0	3.70	.782	.1752	2.486	.4233

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
410.0	2.70	.324	.0135	1.236	.8599
410.0	2.80	.431	.0216	1.280	.7984
410.0	2.90	.514	.0308	1.332	.7427
410.0	3.00	.581	.0411	1.391	.6946
10.0	3.10	.634	.0528	1.459	.6509
410.0	3.20	.677	.0660	1.539	.6115
410.0	3.30	.711	.0808	1.634	.5753
410.0	3.40	.739	.0978	1.751	.5410
410.0	3.50	.761	.1178	1.903	.5075
410.0	3.60	.777	.1427	2.122	.4726
410.0	3.70	.783	.1764	2.501	.4327

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
420.0	2.80	.382	.0186	1.271	.8296
420.0	2.90	.477	.0280	1.324	.7688
420.0	3.00	.552	.0384	1.383	.7177
420.0	3.10	.612	.0504	1.452	.6709
420.0	3.20	.660	.0638	1.534	.6289
420.0	3.30	.700	.0791	1.630	.5907
420.0	3.40	.730	.0965	1.749	.5546
420.0	3.50	.755	.1171	1.904	.5196
420.0	3.60	.775	.1427	2.128	.4833
420.0	3.70	.784	.1775	2.516	.4420

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
430.0	2.80	.327	.0156	1.264	.8595
430.0	2.90	.435	.0249	1.314	.7972
430.0	3.00	.520	.0356	1.375	.7408
430.0	3.10	.587	.0477	1.444	.6917
430.0	3.20	.641	.0614	1.526	.6472
430.0	3.30	.686	.0771	1.626	.6063
430.0	3.40	.720	.0949	1.746	.5686
430.0	3.50	.749	.1161	1.905	.5318
430.0	3.60	.771	.1423	2.131	.4945
430.0	3.70	.784	.1787	2.534	.4509

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
440.0	2.90	.389	.0217	1.305	.8266
440.0	3.00	.484	.0325	1.366	.7657
440.0	3.10	.560	.0446	1.435	.7141
440.0	3.20	.621	.0587	1.519	.6661
440.0	3.30	.670	.0748	1.620	.6227
440.0	3.40	.710	.0932	1.743	.5828
440.0	3.50	.741	.1149	1.904	.5443
440.0	3.60	.767	.1419	2.135	.5054
440.0	3.70	.783	.1795	2.548	.4602

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
450.0	2.90	.337	.0183	1.296	.8560
450.0	3.00	.445	.0291	1.355	.7928
450.0	3.10	.529	.0415	1.426	.7365
450.0	3.20	.597	.0558	1.510	.6857
450.0	3.30	.653	.0722	1.612	.6399
450.0	3.40	.698	.0912	1.738	.5975
450.0	3.50	.733	.1133	1.901	.5574
450.0	3.60	.762	.1412	2.138	.5164
450.0	3.70	.782	.1799	2.557	.4699

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
460.0	2.90	.280	.0148	1.288	.8853
460.0	3.00	.401	.0256	1.345	.8204
460.0	3.10	.496	.0381	1.415	.7601
460.0	3.20	.572	.0525	1.499	.7068
460.0	3.30	.634	.0694	1.602	.6578
460.0	3.40	.684	.0888	1.731	.6129
460.0	3.50	.724	.1117	1.898	.5704
460.0	3.60	.756	.1402	2.139	.5278
460.0	3.70	.780	.1804	2.572	.4790

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
470.0	3.00	.352	.0219	1.333	.8502
470.0	3.10	.459	.0345	1.404	.7857
470.0	3.20	.544	.0490	1.487	.7291
470.0	3.30	.612	.0661	1.593	.6763
470.0	3.40	.669	.0861	1.722	.6289
470.0	3.50	.714	.1097	1.893	.5839
470.0	3.60	.750	.1388	2.136	.5396
470.0	3.70	.778	.1805	2.581	.4886

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
480.0	3.00	.298	.0181	1.325	.8779
480.0	3.10	.418	.0307	1.393	.8115
480.0	3.20	.512	.0454	1.476	.7513
480.0	3.30	.589	.0627	1.581	.6959
480.0	3.40	.652	.0830	1.712	.6456
480.0	3.50	.703	.1074	1.886	.5980
480.0	3.60	.743	.1374	2.136	.5512
480.0	3.70	.775	.1801	2.585	.4987

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
490.0	3.10	.372	.0266	1.380	.8395
490.0	3.20	.478	.0414	1.463	.7753
490.0	3.30	.563	.0588	1.567	.7170
490.0	3.40	.633	.0796	1.700	.6629
490.0	3.50	.690	.1046	1.875	.6131
490.0	3.60	.735	.1356	2.131	.5634
490.0	3.70	.771	.1794	2.587	.5090

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
500.0	3.10	.321	.0224	1.368	.8680
500.0	3.20	.440	.0373	1.451	.7992
500.0	3.30	.535	.0547	1.552	.7391
500.0	3.40	.611	.0759	1.687	.6810
500.0	3.50	.675	.1015	1.864	.6282
500.0	3.60	.726	.1333	2.122	.5764
500.0	3.70	.767	.1787	2.592	.5189

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
510.0	3.10	.265	.0181	1.358	.8960
510.0	3.20	.398	.0329	1.438	.8254
510.0	3.30	.503	.0505	1.538	.7614
510.0	3.40	.588	.0718	1.672	.7006
510.0	3.50	.658	.0979	1.851	.6441
510.0	3.60	.716	.1306	2.110	.5898
510.0	3.70	.762	.1775	2.590	.5294

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
520.0	3.20	.351	.0282	1.422	.8538
520.0	3.30	.468	.0461	1.525	.7834
520.0	3.40	.562	.0674	1.654	.7214
520.0	3.50	.640	.0940	1.835	.6611
520.0	3.60	.705	.1276	2.097	.6037
520.0	3.70	.757	.1755	2.581	.5407

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
530.0	3.20	.299	.0235	1.409	.8811
530.0	3.30	.430	.0414	1.510	.8074
530.0	3.40	.534	.0625	1.634	.7438
530.0	3.50	.620	.0896	1.817	.6789
530.0	3.60	.692	.1241	2.081	.6183
530.0	3.70	.750	.1730	2.565	.5527

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
540.0	3.20	.242	.0185	1.396	.9094
540.0	3.30	.388	.0364	1.493	.8335
540.0	3.40	.503	.0579	1.620	.7639
540.0	3.50	.597	.0849	1.797	.6979
540.0	3.60	.677	.1201	2.063	.6334
540.0	3.70	.742	.1700	2.546	.5651

FLOW CHOKED IN ROTOR PASS NO. 2
TIME, 2 MINUTES AND 58 SECONDS

PROGRAM FOR RUN 6

```
      PROGRAM TURBINE
     0DIMENSION AS(20), DMI(20), DMO(20), ALPHAO(20),AR(20), BETAO(20),
     1ZES2(15), ZS2(15), ZER(15,2), ZR(15,2)  ,ZE(2), Z(2)
     0COMMON GAM, RRATE, RRPM, PROS, TR, UO, BETAI, ALPHAI, PROR, TS,
     1T, P, VM, AS, DMI, DMO, ALPHAO, AR, BETAO, IFLAG, ZES2, ZS2,
     2ZER, ZR, R, L, ZE, Z  , OTA, PR  ,ETAT, PC, PROE, VRATIO,ICR,IBR,
     3DAV , ETAD, AD
      GAM=1.36
      R=55.16
      ETAD=.70
      AD=92.3
      DAV=13.0
     0READ INPUT TAPE 3, 1, (AS(I),I=1,2), (DMI(I),I=1,2),
     1(DMO(I),I=1,2), (AR(I),I=1,2), (ZES2(I),I=1,15),
     2(ZS2(I),I=1,15),((ZER(I,L),I=1,15),L=1,2),((ZR(I,L),I=1,15),L=1,2)
      READ INPUT TAPE 3, 654, (ALPHAO(I),I=1,2), (BETAO(I),I=1,2)
    1 FORMAT (16F5.0)
  654 FORMAT (4F8.0)
   20FORMAT (5H1RRPM,6X,5HRRATE,4X,4HETAT,4X,2HPC,6X,4HPROE,6X,
     16HVRATIO)
      DO 400 J = 240,540,10
      RRPM = J
      WRITE OUTPUT TAPE 4,2
      DO 300 K = 370,430
      B = K
      RRATE = B/100.
      TS=1.
      PROR=1.
      ZE(1) = .2050
      Z(1) = .2475
      ALPHAI = -.74175
      DO 200 L=1,2
      CALL STATOR
      IF(ICR) 18,18,300
   18 IF(IFLAG) 20,20,900
   20 CALL ROTOR
      IF(IBR)19,19,300
   19 IF(IFLAG)200,200,800
  200 CONTINUE
      CALL DIFFU
      WRITE OUTPUT TAPE 4,3, RRPM,RRATE,ETAT, PC, PROE, VRATIO
    3 FORMAT (F6.1, F9.2, F8.3, F7.4, F9.3, F11.4)
  300 CONTINUE
  900 WRITE OUTPUT TAPE 4,10,L
   10 FORMAT (31H FLOW CHOKED IN STATOR PASS NO.I2)
      GO TO 400
  800 WRITE OUTPUT TAPE 4,11,L
   11 FORMAT (30H FLOW CHOKED IN ROTOR PASS NO.I2)
  400 CONTINUE
      END FILE 4
      END
      FUNCTION EXP3 (GAM)
      EXP3 = (GAM -1.) / GAM
      RETURN
      END
      FUNCTION EXP4 (GAM)
      EXP4 = GAM / (GAM-1.)
      RETURN
      END
      FUNCTION C1 (R)
      C1 = SQRTF (R / 32.174)
      RETURN
      END
      FUNCTION C2 (R,GAM)
      C2 = SQRTF (64.348 * R * GAM / (GAM - 1.))
      RETURN
      END
      FUNCTION C3 (R,GAM)
      C3 = 1. / (64.348 * R * GAM /(GAM-1.)) * 1.E4
      RETURN
      END
```

```
      SUBROUTINE STATOR
     0DIMENSION AS(20), DMI(20), DMO(20), ALPHAO(20),AR(20), BETAO(20),
     1ZES2(15), ZS2(15), ZER(15,2), ZR(15,2)   ,ZE(2), Z(2)
     0COMMON GAM, RRATE, RRPM, PROS, TR, UO, BETAI, ALPHAI, PROR, TS,
     1T, P, VM, AS, DMI, DMO, ALPHAO, AR, BETAO, IFLAG, ZES2, ZS2,
     2ZER, ZR, R, L, ZE, Z  , OTA, PR  ,ETAT, PC, PROE, VRATIO,ICR,IBR,
     3DAV , ETAD, AD
      ICR = 0
      OTA =RRATE / PROR * C1(R) / AS(L) * SQRTF (TS)
      B1 = (1.22173 - ALPHAI) / .17453 + 1.
      JB = B1
      BB = JB
      DIFF = B1 - BB
      ZE(2) = (ZES2(JB + 1) - ZES2(JB)) * DIFF + ZES2(JB)
      Z(2) = (ZS2(JB + 1) - ZS2(JB)) * DIFF + ZS2(JB)
      CALL RATIO
      IF (IFLAG) 30, 30, 31
   30 P = PROR / PR
      TIS = PR ** EXP3(GAM)
      DTIS = (TIS - 1.) / TIS
      DTISO = DTIS * TS
      DTO = DTISO * (1. - Z(L))
      T = TS - DTO
      V =C2(R,GAM)*SQRTF (DTO)
      UI = .0043633 * RRPM * DMI(L)
      UO = .0043633 * RRPM * DMO(L)
      VU = V * SINF(ALPHAO(L))
      VM = V * COSF(ALPHAO(L))
      WU = VU - UI
      W = SQRTF (VM * VM + WU *WU)
      DTR = C3 (R,GAM)*(W*W+UO*UO-UI*UI) *1.E-4
      TR = T + DTR
      PRSO = (1. + DTR / T) ** EXP4(GAM)
      PROS = PRSO * P
      BETAI = ATANF (WU / VM)
      IF (1.22173 -ABSF(BETAI))321,31,31
  321 ICR = 1
   31 RETURN
      END
      SUBROUTINE ROTOR
     0DIMENSION AS(20), DMI(20), DMO(20), ALPHAO(20),AR(20), BETAO(20),
     1ZES2(15), ZS2(15), ZER(15,2), ZR(15,2)   ,ZE(2), Z(2)
     0COMMON GAM, RRATE, RRPM, PROS, TR, UO, BETAI, ALPHAI, PROR, TS,
     1T, P, VM, AS, DMI, DMO, ALPHAO, AR, BETAO, IFLAG, ZES2, ZS2,
     2ZER, ZR, R, L, ZE, Z  , OTA, PR  ,ETAT, PC, PROE, VRATIO,ICR,IBR,
     3DAV , ETAD, AD
      IBR = 0
      OTA = RRATE / PROS * C1(R) / AR(L) * SQRTF (TR)
      B1 = ( 1.22173 - BETAI) / .17453 + 1.
      JB = B1
      BB = JB
      DIFF = B1 - BB
      ZE (L) =  (ZER((JB + 1),L) - ZER(JB,L)) * DIFF + ZER(JB,L)
      Z( L) = ( ZR((JB + 1),L) - ZR(JB,L)) * DIFF + ZR(JB,L)
      CALL RATIO
      IF (IFLAG) 40, 40,41
   40 P = PROS / PR
      TIS = PR** EXP 3(GAM)
      DTIS = (TIS - 1.) / TIS
      DTISO = DTIS * TR
      DTO = DTISO * (1. - Z(L))
      T = TR - DTO
      W = C2(R,GAM)*SQRTF (DTO)
      WU = W * SINF (BETAO(L))
      VM = W * COSF (BETAO(L))
      VU = WU + UO
      V = SQRTF (VM * VM + VU * VU)
      DTS = C3(R,GAM) * V*V*1.E-4
      TS = T + DTS
      PRRO = (1. + DTS /T) ** EXP4(GAM)
      PROR = PRRO * P
      ALPHAI = ATANF (VU / VM)
      IF (1.22173 - ABSF(ALPHAI))322,41,41
  322 IBR = 1
   41 RETURN
      END
```

```
      SUBROUTINE DIFFU
     0DIMENSION AS(20), DMI(20), DMO(20), ALPHAO(20),AR(20), BETAO(20),
     1ZES2(15), ZS2(15), ZER(15,2), ZR(15,2)  ,ZE(2), Z(2)
     0COMMON GAM, RRATE, RRPM, PROS, TR, UO, BETAI, ALPHAI, PROR, TS,
     1T, P, VM, AS, DMI, DMO, ALPHAO, AR, BETAO, IFLAG, ZES2, ZS2,
     2ZER, ZR, R, L, ZE, Z  , OTA, PR  ,ETAT, PC, PROE, VRATIO,ICR,IBR,
     3DAV , ETAD, AD
      ETADA = ETAD * COSF (ALPHAI) **2.
      DTW = 1. - TS
      CP = R / 778.17 * GAM / (GAM - 1.)
      PC = RRATE * CP * DTW * 1.055
      VD = RRATE * R / AD * T / P
      DTD = C3(R,GAM) * ETADA * (VM * VM - VD * VD) *1.E-4
      PRE = (1. + DTD / T) ** EXP4(GAM)
      PREO = PRE * P
      PROE = 1. / PREO
      DTT = 1. - PREO ** EXP3(GAM)
      ETAT = DTW / DTT
      VRATIO = .0043633 / C2(R,GAM) * RRPM*DAV / SQRTF (DTT)
      RETURN
      END
      SUBROUTINE RATIO
     0DIMENSION AS(20), DMI(20), DMO(20), ALPHAO(20),AR(20), BETAO(20),
     1ZES2(15), ZS2(15), ZER(15,2), ZR(15,2)  ,ZE(2), Z(2)
     0COMMON GAM, RRATE, RRPM, PROS, TR, UO, BETAI, ALPHAI, PROR, TS,
     1T, P, VM, AS, DMI, DMO, ALPHAO, AR, BETAO, IFLAG, ZES2, ZS2,
     2ZER, ZR, R, L, ZE, Z  , OTA, PR  ,ETAT, PC, PROE, VRATIO,ICR,IBR,
     3DAV , ETAD, AD
      IFLAG = 0
      EN = GAM / (1. + ZE(L) * (GAM - 1.))
      EXP1 = 2./EN
      EXP2 = (EN+1.) /EN
      EXP5 = EN/(EN-1.)
      PRC = ((EN + 1.) /2.)** EXP5
      DUNM = 1. / (PRC**EXP1)
      DUGM = 1./(PRC**EXP2)
      OTM = SQRTF (2.*GAM/(GAM-1.)*(DUNM-DUGM))
      IF (OTA-OTM)60,61,61
   60 A = 1. - 3.*(GAM - 1.)/GAM* 1./(EN-1.) * OTA **2.
      IF(A) 52,53,51
   51 A = SQRTF(A)
      GO TO 53
   52 A = 0.
   53 PRA = 1./(1. - EN/3. * (1. -A))
      IF (PRA - PRC) 62,63,63
   63 PRA = PRA - .05
   62 DUN = 1./(PRA ** EXP1)
      DUG = 1./(PRA ** EXP2)
      OT = SQRTF (2.*GAM /(GAM - 1.) * (DUN - DUG))
      IF (OT - OTA)64,65,68
   65 PR = PRA
      RETURN
   64 DO 66 I = 1,500
      PRA = PRA + .0001
      DUN = 1. / (PRA ** EXP1)
      DUG = 1. / (PRA ** EXP2)
      OT = SQRTF (ABSF (2. * GAM / (GAM - 1.) * (DUN - DUG)))
      IF (OT-OTA)66,65,67
   66 CONTINUE
   67 PR = PRA
      RETURN
   68 DO 69 I = 1,500
      PRA = PRA - .0001
      DUN = 1. /(PRA**EXP 1)
      DUG = 1./(PRA ** EXP2)
      OT = SQRTF (ABSF (2. * GAM / (GAM - 1.) * (DUN - DUG)))
      IF (OT-OTA) 70,65,69
   69 CONTINUE
   70 PR = PRA
      RETURN
   61 IFLAG = 1
      END
      END
```

RESULTS OF RUN 6

RRPM	RRATE	ETAT	PC	PROE	VRATIO
240.0	3.70	.702	.1306	2.096	.2788
240.0	3.71	.700	.1324	2.120	.2768
240.0	3.72	.698	.1343	2.145	.2749
240.0	3.73	.696	.1362	2.172	.2729
240.0	3.74	.694	.1382	2.200	.2708
240.0	3.75	.692	.1402	2.231	.2688
240.0	3.76	.689	.1423	2.263	.2667
240.0	3.77	.686	.1446	2.299	.2644
240.0	3.78	.684	.1468	2.336	.2621
240.0	3.79	.680	.1492	2.377	.2598
240.0	3.80	.677	.1518	2.422	.2573
240.0	3.81	.674	.1544	2.472	.2547
240.0	3.82	.670	.1573	2.527	.2520
240.0	3.83	.665	.1603	2.591	.2491
240.0	3.84	.660	.1636	2.664	.2460
240.0	3.85	.654	.1673	2.751	.2425
240.0	3.86	.648	.1713	2.856	.2387
240.0	3.87	.639	.1762	2.999	.2341
240.0	3.88	.612	.1861	3.414	.2232

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
250.0	3.70	.711	.1347	2.130	.2875
250.0	3.71	.709	.1367	2.156	.2855
250.0	3.72	.707	.1387	2.184	.2834
250.0	3.73	.704	.1407	2.213	.2812
250.0	3.74	.702	.1429	2.244	.2790
250.0	3.75	.700	.1451	2.277	.2768
250.0	3.76	.697	.1474	2.313	.2745
250.0	3.77	.694	.1498	2.351	.2721
250.0	3.78	.691	.1522	2.393	.2696
250.0	3.79	.688	.1548	2.439	.2671
250.0	3.80	.685	.1576	2.489	.2645
250.0	3.81	.681	.1605	2.544	.2617
250.0	3.82	.677	.1636	2.608	.2587
250.0	3.83	.672	.1671	2.683	.2554
250.0	3.84	.666	.1708	2.771	.2518
250.0	3.85	.659	.1750	2.880	.2478
250.0	3.86	.650	.1800	3.024	.2430
250.0	3.87	.624	.1901	3.432	.2320

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
260.0	3.70	.718	.1387	2.163	.2963
260.0	3.71	.716	.1408	2.191	.2941
260.0	3.72	.714	.1429	2.221	.2919
260.0	3.73	.712	.1452	2.253	.2896
260.0	3.74	.710	.1474	2.287	.2872
260.0	3.75	.707	.1498	2.323	.2848
260.0	3.76	.704	.1523	2.362	.2823
260.0	3.77	.701	.1549	2.405	.2797
260.0	3.78	.698	.1576	2.452	.2770
260.0	3.79	.695	.1604	2.503	.2743
260.0	3.80	.691	.1635	2.560	.2713
260.0	3.81	.687	.1667	2.625	.2682
260.0	3.82	.682	.1702	2.700	.2649
260.0	3.83	.676	.1741	2.790	.2611
260.0	3.84	.670	.1784	2.900	.2570
260.0	3.85	.661	.1836	3.047	.2520
260.0	3.86	.636	.1937	3.447	.2410

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
270.0	3.70	.726	.1425	2.194	.3052
270.0	3.71	.724	.1447	2.225	.3028
270.0	3.72	.722	.1470	2.257	.3004
270.0	3.73	.719	.1494	2.291	.2980
270.0	3.74	.717	.1518	2.328	.2954
270.0	3.75	.714	.1544	2.368	.2928
270.0	3.76	.712	.1571	2.411	.2901
270.0	3.77	.708	.1599	2.458	.2873
270.0	3.78	.705	.1628	2.510	.2844
270.0	3.79	.701	.1660	2.569	.2813
270.0	3.80	.697	.1693	2.634	.2781
270.0	3.81	.693	.1729	2.710	.2746
270.0	3.82	.687	.1769	2.800	.2708
270.0	3.83	.680	.1814	2.912	.2664
270.0	3.84	.671	.1867	3.061	.2613
270.0	3.85	.647	.1971	3.462	.2499

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
280.0	3.70	.733	.1461	2.224	.3141
280.0	3.71	.731	.1485	2.256	.3116
280.0	3.72	.729	.1509	2.291	.3090
280.0	3.73	.726	.1534	2.328	.3064
280.0	3.74	.724	.1561	2.368	.3037
280.0	3.75	.721	.1588	2.411	.3009
280.0	3.76	.718	.1617	2.458	.2980
280.0	3.77	.715	.1647	2.511	.2949
280.0	3.78	.712	.1679	2.568	.2918
280.0	3.79	.708	.1713	2.634	.2884
280.0	3.80	.703	.1750	2.710	.2848
280.0	3.81	.698	.1791	2.799	.2809
280.0	3.82	.691	.1836	2.909	.2764
280.0	3.83	.683	.1890	3.054	.2712
280.0	3.84	.657	.2001	3.470	.2589

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
290.0	3.70	.739	.1496	2.255	.3228
290.0	3.71	.737	.1521	2.289	.3202
290.0	3.72	.735	.1546	2.325	.3176
290.0	3.73	.733	.1573	2.364	.3148
290.0	3.74	.730	.1601	2.407	.3119
290.0	3.75	.728	.1630	2.454	.3089
290.0	3.76	.725	.1661	2.505	.3058
290.0	3.77	.721	.1694	2.562	.3025
290.0	3.78	.718	.1728	2.626	.2991
290.0	3.79	.713	.1766	2.700	.2954
290.0	3.80	.708	.1807	2.787	.2914
290.0	3.81	.702	.1853	2.893	.2869
290.0	3.82	.695	.1906	3.029	.2817
290.0	3.83	.680	.1982	3.269	.2738

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
300.0	3.70	.745	.1530	2.284	.3316
300.0	3.71	.743	.1556	2.320	.3288
300.0	3.72	.741	.1583	2.359	.3260
300.0	3.73	.739	.1611	2.401	.3230
300.0	3.74	.736	.1641	2.447	.3200
300.0	3.75	.733	.1672	2.498	.3168
300.0	3.76	.730	.1705	2.553	.3135
300.0	3.77	.727	.1740	2.616	.3100
300.0	3.78	.723	.1777	2.687	.3063
300.0	3.79	.718	.1818	2.771	.3022
300.0	3.80	.713	.1864	2.871	.2977
300.0	3.81	.706	.1916	2.998	.2926
300.0	3.82	.696	.1980	3.176	.2862
300.0	3.83	.676	.2081	3.542	.2755

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
310.0	3.70	.751	.1560	2.310	.3406
310.0	3.71	.749	.1588	2.349	.3376
310.0	3.72	.747	.1617	2.391	.3345
310.0	3.73	.744	.1647	2.436	.3314
310.0	3.74	.742	.1679	2.486	.3281
310.0	3.75	.739	.1712	2.541	.3247
310.0	3.76	.735	.1747	2.602	.3211
310.0	3.77	.732	.1785	2.672	.3173
310.0	3.78	.728	.1826	2.752	.3132
310.0	3.79	.722	.1872	2.848	.3087
310.0	3.80	.716	.1922	2.965	.3037
310.0	3.81	.708	.1983	3.122	.2977
310.0	3.82	.686	.2095	3.512	.2855

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
320.0	3.70	.756	.1589	2.335	.3496
320.0	3.71	.754	.1618	2.376	.3465
320.0	3.72	.752	.1649	2.420	.3432
320.0	3.73	.750	.1680	2.468	.3399
320.0	3.74	.747	.1714	2.522	.3363
320.0	3.75	.744	.1750	2.582	.3327
320.0	3.76	.741	.1787	2.648	.3288
320.0	3.77	.737	.1829	2.726	.3246
320.0	3.78	.732	.1874	2.817	.3201
320.0	3.79	.726	.1924	2.926	.3151
320.0	3.80	.719	.1982	3.069	.3093
320.0	3.81	.704	.2072	3.341	.2998

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
330.0	3.70	.761	.1616	2.359	.3586
330.0	3.71	.759	.1647	2.402	.3553
330.0	3.72	.757	.1679	2.449	.3519
330.0	3.73	.755	.1712	2.499	.3484
330.0	3.74	.752	.1748	2.557	.3446
330.0	3.75	.749	.1786	2.621	.3407
330.0	3.76	.745	.1826	2.693	.3366
330.0	3.77	.741	.1871	2.778	.3321
330.0	3.78	.736	.1919	2.879	.3272
330.0	3.79	.730	.1975	3.005	.3216
330.0	3.80	.721	.2042	3.181	.3147
330.0	3.81	.703	.2151	3.542	.3031

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
340.0	3.70	.765	.1642	2.382	.3676
340.0	3.71	.763	.1674	2.428	.3641
340.0	3.72	.761	.1708	2.477	.3605
340.0	3.73	.759	.1743	2.530	.3568
340.0	3.74	.756	.1781	2.591	.3529
340.0	3.75	.753	.1821	2.659	.3487
340.0	3.76	.750	.1863	2.737	.3443
340.0	3.77	.745	.1912	2.831	.3394
340.0	3.78	.740	.1965	2.945	.3340
340.0	3.79	.733	.2028	3.094	.3276
340.0	3.80	.715	.2137	3.428	.3157

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
350.0	3.70	.769	.1665	2.402	.3768
350.0	3.71	.768	.1699	2.450	.3731
350.0	3.72	.766	.1734	2.502	.3693
350.0	3.73	.763	.1771	2.559	.3654
350.0	3.74	.761	.1812	2.625	.3611
350.0	3.75	.758	.1854	2.697	.3567
350.0	3.76	.754	.1900	2.782	.3520
350.0	3.77	.749	.1952	2.885	.3467
350.0	3.78	.743	.2010	3.013	.3407
350.0	3.79	.735	.2081	3.189	.3335
350.0	3.80	.717	.2196	3.556	.3210

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
360.0	3.70	.773	.1686	2.421	.3861
360.0	3.71	.772	.1722	2.470	.3822
360.0	3.72	.770	.1759	2.525	.3782
360.0	3.73	.767	.1798	2.585	.3740
360.0	3.74	.765	.1840	2.654	.3696
360.0	3.75	.762	.1885	2.732	.3649
360.0	3.76	.758	.1934	2.823	.3598
360.0	3.77	.753	.1990	2.937	.3540
360.0	3.78	.747	.2055	3.083	.3473
360.0	3.79	.734	.2150	3.344	.3372

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
370.0	3.70	.777	.1705	2.438	.3954
370.0	3.71	.775	.1742	2.489	.3914
370.0	3.72	.773	.1781	2.545	.3872
370.0	3.73	.771	.1822	2.608	.3828
370.0	3.74	.177	.1867	2.682	.1812
370.0	3.75	.765	.1914	2.766	.3730
370.0	3.76	.762	.1967	2.865	.3676
370.0	3.77	.756	.2027	2.990	.3613
370.0	3.78	.749	.2099	3.157	.3538
370.0	3.79	.730	.2232	3.559	.3393

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
380.0	3.70	.779	.1722	2.453	.4048
380.0	3.71	.778	.1761	2.507	.4006
380.0	3.72	.776	.1801	2.566	.3962
380.0	3.73	.774	.1844	2.631	.3916
380.0	3.74	.772	.1891	2.707	.3867
380.0	3.75	.769	.1941	2.796	.3814
380.0	3.76	.765	.1997	2.901	.3756
380.0	3.77	.760	.2062	3.038	.3687
380.0	3.78	.752	.2143	3.232	.3603
380.0	3.79	.732	.2283	3.668	.3450

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
390.0	3.70	.781	.1737	2.470	.4141
390.0	3.71	.780	.1778	2.525	.4097
390.0	3.72	.779	.1820	2.585	.4052
390.0	3.73	.777	.1864	2.652	.4005
390.0	3.74	.775	.1912	2.731	.3953
390.0	3.75	.772	.1966	2.825	.3897
390.0	3.76	.768	.2026	2.939	.3834
390.0	3.77	.763	.2096	3.089	.3760
390.0	3.78	.752	.2199	3.351	.3650

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
400.0	3.70	.782	.1752	2.486	.4233
400.0	3.71	.782	.1794	2.544	.4187
400.0	3.72	.781	.1838	2.608	.4139
400.0	3.73	.779	.1885	2.679	.4089
400.0	3.74	.777	.1937	2.763	.4034
400.0	3.75	.775	.1994	2.862	.3975
400.0	3.76	.771	.2057	2.984	.3909
400.0	3.77	.765	.2133	3.149	.3829
400.0	3.78	.747	.2281	3.568	.3665

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
410.0	3.70	.783	.1764	2.501	.4327
410.0	3.71	.783	.1808	2.560	.4279
410.0	3.72	.782	.1854	2.626	.4229
410.0	3.73	.781	.1903	2.701	.4176
410.0	3.74	.779	.1958	2.791	.4117
410.0	3.75	.776	.2018	2.897	.4054
410.0	3.76	.773	.2087	3.030	.3982
410.0	3.77	.766	.2173	3.222	.3892
410.0	3.78	.751	.2311	3.611	.3742

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
420.0	3.70	.784	.1775	2.516	.4420
420.0	3.71	.784	.1820	2.576	.4371
420.0	3.72	.783	.1867	2.642	.4320
420.0	3.73	.782	.1918	2.720	.4265
420.0	3.74	.781	.1976	2.814	.4203
420.0	3.75	.778	.2040	2.928	.4135
420.0	3.76	.774	.2114	3.073	.4058
420.0	3.77	.767	.2212	3.296	.3954

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
430.0	3.70	.784	.1787	2.534	.4509
430.0	3.71	.784	.1834	2.598	.4458
430.0	3.72	.784	.1884	2.668	.4404
430.0	3.73	.783	.1938	2.750	.4346
430.0	3.74	.781	.1998	2.849	.4282
430.0	3.75	.779	.2065	2.967	.4211
430.0	3.76	.775	.2144	3.124	.4128
430.0	3.77	.763	.2290	3.493	.3968

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
440.0	3.70	.783	.1795	2.548	.4602
440.0	3.71	.783	.1845	2.615	.4548
440.0	3.72	.784	.1897	2.690	.4490
440.0	3.73	.783	.1954	2.776	.4429
440.0	3.74	.782	.2019	2.882	.4360
440.0	3.75	.780	.2091	3.013	.4283
440.0	3.76	.776	.2180	3.193	.4190
440.0	3.77	.763	.2334	3.593	.4022

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
450.0	3.70	.782	.1799	2.557	.4699
450.0	3.71	.783	.1851	2.627	.4641
450.0	3.72	.783	.1906	2.705	.4581
450.0	3.73	.783	.1966	2.796	.4516
450.0	3.74	.782	.2035	2.909	.4442
450.0	3.75	.780	.2114	3.051	.4359
450.0	3.76	.776	.2212	3.257	.4255

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
460.0	3.70	.780	.1804	2.572	.4790
460.0	3.71	.781	.1858	2.643	.4731
460.0	3.72	.782	.1915	2.723	.4669
460.0	3.73	.783	.1978	2.817	.4602
460.0	3.74	.782	.2049	2.934	.4525
460.0	3.75	.781	.2131	3.083	.4439
460.0	3.76	.776	.2243	3.321	.4319

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
470.0	3.70	.778	.1805	2.581	.4886
470.0	3.71	.779	.1861	2.655	.4824
470.0	3.72	.781	.1921	2.739	.4758
470.0	3.73	.782	.1988	2.840	.4686
470.0	3.74	.781	.2065	2.965	.4604
470.0	3.75	.780	.2155	3.131	.4508
470.0	3.76	.770	.2342	3.580	.4301

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
480.0	3.70	.775	.1801	2.585	.4987
480.0	3.71	.777	.1859	2.661	.4922
480.0	3.72	.779	.1922	2.748	.4852
480.0	3.73	.780	.1993	2.853	.4776
480.0	3.74	.781	.2074	2.987	.4689
480.0	3.75	.779	.2173	3.169	.4584
480.0	3.76	.771	.2352	3.592	.4388

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
490.0	3.70	.771	.1794	2.587	.5090
490.0	3.71	.774	.1853	2.663	.5023
490.0	3.72	.777	.1918	2.752	.4951
490.0	3.73	.778	.1991	2.859	.4872
490.0	3.74	.780	.2076	2.996	.4781
490.0	3.75	.779	.2181	3.187	.4669
490.0	3.76	.772	.2358	3.598	.4477

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
500.0	3.70	.767	.1787	2.592	.5189
500.0	3.71	.771	.1849	2.669	.5120
500.0	3.72	.774	.1916	2.760	.5046
500.0	3.73	.776	.1991	2.869	.4964
500.0	3.74	.778	.2079	3.008	.4870
500.0	3.75	.778	.2186	3.202	.4757
500.0	3.76	.773	.2368	3.620	.4559

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
510.0	3.70	.762	.1775	2.590	.5294
510.0	3.71	.766	.1839	2.671	.5221
510.0	3.72	.770	.1909	2.762	.5145
510.0	3.73	.773	.1987	2.874	.5059
510.0	3.74	.776	.2081	3.022	.4959
510.0	3.75	.777	.2197	3.233	.4835

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
520.0	3.70	.757	.1755	2.581	.5407
520.0	3.71	.761	.1822	2.663	.5330
520.0	3.72	.766	.1895	2.757	.5250
520.0	3.73	.770	.1976	2.871	.5161
520.0	3.74	.774	.2073	3.020	.5057
520.0	3.75	.775	.2197	3.240	.4925

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
530.0	3.70	.750	.1730	2.565	.5527
530.0	3.71	.756	.1798	2.646	.5448
530.0	3.72	.761	.1873	2.741	.5364
530.0	3.73	.766	.1957	2.856	.5271
530.0	3.74	.770	.2056	3.005	.5165
530.0	3.75	.773	.2182	3.221	.5031

FLOW CHOKED IN ROTOR PASS NO. 2

RRPM	RRATE	ETAT	PC	PROE	VRATIO
540.0	3.70	.742	.1700	2.546	.5651
540.0	3.71	.748	.1769	2.626	.5570
540.0	3.72	.754	.1843	2.716	.5487
540.0	3.73	.760	.1928	2.830	.5392
540.0	3.74	.766	.2030	2.977	.5282
540.0	3.75	.771	.2155	3.184	.5148
540.0	3.76	.770	.2396	3.703	.4888

FLOW CHOKED IN ROTOR PASS NO. 2
TIME, 6 MINUTES AND 48 SECONDS

RESULTS OF RUN 7

RRPM	RRATE	ETAT	PC	PACE	VRATIO
441.8	2.56	.292	.0121	1.249	.9058
441.8	2.57	.306	.0129	1.253	.8982
441.8	2.58	.319	.0137	1.258	.8908
441.8	2.59	.332	.0146	1.263	.8836
441.8	2.60	.345	.0154	1.268	.8763
441.8	2.61	.357	.0163	1.273	.8692
441.8	2.62	.369	.0172	1.278	.8630
441.8	2.63	.381	.0181	1.283	.8562
441.8	2.64	.392	.0190	1.288	.8497
441.8	2.65	.403	.0199	1.294	.8433
441.8	2.66	.414	.0208	1.299	.8371
441.8	2.67	.425	.0217	1.304	.8307
441.8	2.68	.435	.0227	1.309	.8249
441.8	2.69	.445	.0236	1.314	.8191
441.8	2.70	.455	.0246	1.320	.8133
441.8	2.71	.465	.0256	1.325	.8076
441.8	2.72	.474	.0265	1.331	.8020
441.8	2.73	.484	.0275	1.336	.7965
441.8	2.74	.493	.0285	1.342	.7911
441.8	2.75	.502	.0296	1.347	.7858
441.8	2.76	.511	.0306	1.353	.7804
441.8	2.77	.519	.0317	1.359	.7752
441.8	2.78	.528	.0327	1.365	.7700
441.8	2.79	.536	.0338	1.371	.7649
441.8	2.80	.544	.0350	1.377	.7594
441.8	2.81	.552	.0362	1.384	.7536
441.8	2.82	.560	.0374	1.392	.7478
441.8	2.83	.568	.0386	1.399	.7423
441.8	2.84	.575	.0398	1.406	.7368
441.8	2.85	.582	.0410	1.414	.7314
441.8	2.86	.589	.0423	1.421	.7261
441.8	2.87	.596	.0436	1.429	.7209
441.8	2.88	.603	.0449	1.436	.7158
441.8	2.89	.610	.0461	1.444	.7108
441.8	2.90	.616	.0474	1.452	.7060
441.8	2.91	.622	.0487	1.460	.7012
441.8	2.92	.629	.0501	1.468	.6964
441.8	2.93	.635	.0514	1.476	.6917
441.8	2.94	.641	.0528	1.484	.6871
441.8	2.95	.647	.0542	1.492	.6825
441.8	2.96	.653	.0556	1.501	.6780
441.8	2.97	.658	.0570	1.510	.6734
441.8	2.98	.663	.0584	1.518	.6689
441.8	2.99	.668	.0599	1.528	.6645
441.8	3.00	.673	.0614	1.537	.6599
441.8	3.01	.678	.0629	1.547	.6550
441.8	3.02	.683	.0645	1.558	.6503
441.8	3.03	.687	.0661	1.568	.6458
441.8	3.04	.692	.0677	1.579	.6413
441.8	3.05	.696	.0693	1.590	.6367
441.8	3.06	.701	.0710	1.601	.6322
441.8	3.07	.705	.0727	1.613	.6278
441.8	3.08	.709	.0744	1.624	.6235
441.8	3.09	.713	.0761	1.636	.6192
441.8	3.10	.718	.0778	1.648	.6149
441.8	3.11	.722	.0796	1.660	.6107
441.8	3.12	.726	.0814	1.673	.6066
441.8	3.13	.730	.0833	1.685	.6024
441.8	3.14	.734	.0852	1.699	.5982
441.8	3.15	.737	.0871	1.713	.5940
441.8	3.16	.741	.0891	1.727	.5898
441.8	3.17	.745	.0912	1.742	.5856
441.8	3.18	.749	.0932	1.756	.5815
441.8	3.19	.753	.0953	1.772	.5773
441.8	3.20	.757	.0975	1.787	.5733
441.8	3.21	.760	.0997	1.804	.5692

RESULTS OF RUN 7 (cont.)

441.8	3.22	.764	.1019	1.820	.5652
441.8	3.23	.768	.1041	1.837	.5613
441.8	3.24	.771	.1064	1.855	.5572
441.8	3.25	.774	.1087	1.873	.5531
441.8	3.26	.777	.1111	1.892	.5490
441.8	3.27	.779	.1135	1.912	.5450
441.8	3.28	.782	.1160	1.933	.5409
441.8	3.29	.785	.1185	1.954	.5370
441.8	3.30	.788	.1212	1.976	.5329
441.8	3.31	.791	.1238	1.998	.5290
441.8	3.32	.793	.1265	2.022	.5249
441.8	3.33	.796	.1294	2.048	.5206
441.8	3.34	.798	.1323	2.075	.5164
441.8	3.35	.800	.1353	2.103	.5120
441.8	3.36	.803	.1384	2.133	.5077
441.8	3.37	.805	.1416	2.164	.5034
441.8	3.38	.807	.1449	2.197	.4990
441.8	3.39	.809	.1484	2.233	.4945
441.8	3.40	.811	.1519	2.270	.4899
441.8	3.41	.812	.1556	2.311	.4853
441.8	3.42	.814	.1594	2.353	.4807
441.8	3.43	.816	.1635	2.400	.4758
441.8	3.44	.817	.1677	2.451	.4709
441.8	3.45	.818	.1722	2.506	.4656
441.8	3.46	.818	.1769	2.570	.4603
441.8	3.47	.819	.1819	2.641	.4546
441.8	3.48	.819	.1873	2.721	.4486
441.8	3.49	.818	.1932	2.813	.4422
441.8	3.50	.816	.1999	2.930	.4349
441.8	3.51	.813	.2075	3.079	.4265
441.8	3.52	.807	.2170	3.289	.4162
441.8	3.53	.792	.2330	3.747	.3984

FLOW CHOKED IN ROTOR PASS NO. 2
TIME, 0 MINUTES AND 58 SECONDS

RESULTS OF RUN 8

RRPM	RRATE	ETAT	PT	P/OF	VRATIO
420.9	2.68	.167	.0056	1.204	.9511
420.9	2.69	.172	.0062	1.208	.9443
420.9	2.70	.177	.0067	1.212	.9363
420.9	2.71	.202	.0076	1.216	.9285
420.9	2.72	.216	.0083	1.220	.9215
420.9	2.73	.230	.0090	1.224	.9143
420.9	2.74	.243	.0097	1.227	.9073
420.9	2.75	.257	.0105	1.231	.9004
420.9	2.76	.271	.0112	1.235	.8934
420.9	2.77	.282	.0119	1.239	.8870
420.9	2.78	.294	.0127	1.243	.8806
420.9	2.79	.306	.0134	1.248	.8742
420.9	2.80	.317	.0142	1.252	.8680
420.9	2.81	.329	.0149	1.256	.8617
420.9	2.82	.340	.0157	1.260	.8557
420.9	2.83	.351	.0165	1.264	.8501
420.9	2.84	.361	.0173	1.268	.8443
420.9	2.85	.372	.0181	1.272	.8386
420.9	2.86	.382	.0189	1.277	.8331
420.9	2.87	.392	.0197	1.281	.8276
420.9	2.88	.401	.0205	1.286	.8217
420.9	2.89	.411	.0214	1.290	.8159
420.9	2.90	.420	.0223	1.296	.8099
420.9	2.91	.429	.0232	1.301	.8052
420.9	2.92	.438	.0241	1.306	.7990
420.9	2.93	.447	.0251	1.311	.7923
420.9	2.94	.456	.0260	1.317	.7867
420.9	2.95	.464	.0267	1.322	.7812
420.9	2.96	.472	.0277	1.327	.7753
420.9	2.97	.480	.0283	1.332	.7707
420.9	2.98	.488	.0298	1.338	.7655
420.9	2.99	.495	.0308	1.343	.7604
420.9	3.00	.503	.0318	1.349	.7554
420.9	3.01	.510	.0328	1.354	.7504
420.9	3.02	.516	.0338	1.360	.7453
420.9	3.03	.525	.0348	1.366	.7405
420.9	3.04	.532	.0359	1.372	.7353
420.9	3.05	.539	.0370	1.378	.7304
420.9	3.06	.545	.0380	1.384	.7256
420.9	3.07	.552	.0391	1.391	.7209
420.9	3.08	.558	.0402	1.397	.7162
420.9	3.09	.564	.0414	1.403	.7117
420.9	3.10	.571	.0425	1.410	.7071
420.9	3.11	.577	.0437	1.416	.7024
420.9	3.12	.583	.0447	1.424	.6976
420.9	3.13	.589	.0461	1.431	.6928
420.9	3.14	.594	.0473	1.438	.6883
420.9	3.15	.600	.0485	1.445	.6833
420.9	3.16	.605	.0498	1.453	.6792
420.9	3.17	.611	.0511	1.461	.6747
420.9	3.18	.616	.0524	1.468	.6703
420.9	3.19	.621	.0537	1.476	.6657
420.9	3.20	.627	.0550	1.484	.6616
420.9	3.21	.632	.0564	1.492	.6578
420.9	3.22	.637	.0577	1.500	.6532
420.9	3.23	.642	.0591	1.508	.6490
420.9	3.24	.646	.0604	1.517	.6455
420.9	3.25	.651	.0617	1.525	.6410
420.9	3.26	.656	.0633	1.533	.6370
420.9	3.27	.660	.0647	1.542	.6331
420.9	3.28	.665	.0662	1.551	.6291
420.9	3.29	.669	.0676	1.560	.6253
420.9	3.30	.674	.0691	1.569	.6214
420.9	3.31	.678	.0707	1.578	.6175
420.9	3.32	.682	.0723	1.589	.6136
420.9	3.33	.686	.0738	1.598	.6098

RESULTS OF RUN 8 (cont.)

420.9	3.34	.691	.0754	1.608	.6[illegible]
420.9	3.35	.695	.0770	1.617	.6025
420.9	3.36	.699	.0787	1.629	.5736
420.9	3.37	.703	.0803	1.573	.5952
420.9	3.38	.707	.0820	1.650	.[illegible]213
420.9	3.39	.710	.0837	1.661	.5979
420.9	3.40	.714	.0854	1.672	.5841
420.9	3.41	.717	.0870	1.684	.5793
420.9	3.42	.721	.0887	1.695	.5759
420.9	3.43	.724	.0907	1.707	.5734
420.9	3.44	.727	.0925	1.720	.5698
420.9	3.45	.730	.0943	1.732	.5663
420.9	3.46	.733	.0962	1.745	.5628
420.9	3.47	.737	.0981	1.757	.5594
420.9	3.48	.740	.1002	1.771	.5561
420.9	3.49	.743	.1017	1.784	.5526
420.9	3.50	.745	.1037	1.798	.5491
420.9	3.51	.748	.1060	1.813	.5456
420.9	3.52	.751	.1080	1.828	.5422
420.9	3.53	.754	.1101	1.843	.5389
420.9	3.54	.757	.1122	1.859	.5354
420.9	3.55	.759	.1144	1.876	.5318
420.9	3.56	.761	.1166	1.893	.5283
420.9	3.57	.764	.1189	1.911	.5248
420.9	3.58	.766	.1212	1.930	.5212
420.9	3.59	.768	.1235	1.949	.5176
420.9	3.60	.770	.1257	1.969	.5141
420.9	3.61	.772	.1284	1.990	.5108
420.9	3.62	.774	.1307	2.011	.5073
420.9	3.63	.775	.1335	2.033	.5035
420.9	3.64	.777	.1361	2.057	.4996
420.9	3.65	.779	.1388	2.081	.4959
420.9	3.66	.781	.1416	2.107	.4922
420.9	3.67	.782	.1444	2.133	.4885
420.9	3.68	.783	.1474	2.162	.4846
420.9	3.69	.785	.1505	2.192	.4807
420.9	3.70	.786	.1536	2.224	.4768
420.9	3.71	.787	.1568	2.257	.4729
420.9	3.72	.788	.1602	2.298	.4687
420.9	3.73	.789	.1637	2.332	.4645
420.9	3.74	.789	.1673	2.373	.4604
420.9	3.75	.790	.1711	2.419	.4559
420.9	3.76	.790	.1752	2.469	.4513
420.9	3.77	.790	.1794	2.524	.4465
420.9	3.78	.790	.1840	2.586	.4414
420.9	3.79	.789	.1888	2.656	.4361
420.9	3.80	.787	.1941	2.737	.4303
420.9	3.81	.785	.2000	2.835	.4239
420.9	3.82	.782	.2066	2.955	.4157
420.9	3.83	.777	.2147	3.120	.4060
420.9	3.84	.774	.2279	3.456	.3953

FLOW CHOKED IN ROTOR PASS NO. 2
TIME, 1 MINUTES AND 11 SECONDS

<u>RESULTS OF RUN 9</u>

RRPM	RRATE	E[illegible]	[illegible]	[illegible]	[illegible]RATIO
420.9	2.80	.259	.0110	1.23[illegible]	.8993
420.9	2.81	.273	.0118	1.242	.8[illegible]2[illegible]
420.9	2.82	.286	.0126	1.246	.8766
420.9	2.83	.298	.0134	1.250	.8702
420.9	2.84	.311	.0142	1.254	.8640
420.9	2.85	.323	.0151	1.258	.85[illegible]
420.9	2.86	.335	.0159	1.263	.8521
420.9	2.87	.346	.0167	1.267	.8463
420.9	2.88	.357	.0175	1.271	.8406
420.9	2.89	.368	.0183	1.275	.8350
420.9	2.90	.379	.0192	1.280	.8296
420.9	2.91	.389	.0201	1.285	.8223
420.9	2.92	.399	.0210	1.290	.8161
420.9	2.93	.409	.0219	1.295	.8100
420.9	2.94	.419	.0227	1.301	.8041
420.9	2.95	.428	.0236	1.306	.7983
420.9	2.96	.438	.0246	1.311	.7926
420.9	2.97	.447	.0257	1.316	.7870
420.9	2.98	.455	.0267	1.322	.7815
420.9	2.99	.464	.0277	1.327	.7762
420.9	3.00	.472	.0286	1.332	.7702
420.9	3.01	.481	.0296	1.338	.755[illegible]
420.9	3.02	.489	.0307	1.343	.7604
420.9	3.03	.497	.0317	1.349	.7551
420.9	3.04	.504	.0327	1.355	.7499
420.9	3.05	.512	.0338	1.361	.74[illegible]
420.9	3.06	.519	.0348	1.366	.7401
420.9	3.07	.526	.0359	1.372	.7351
420.9	3.08	.533	.0370	1.379	.7303
420.9	3.09	.540	.0381	1.385	.7255
420.9	3.10	.547	.0392	1.391	.720[illegible]
420.9	3.11	.554	.0403	1.397	.7162
420.9	3.12	.560	.0415	1.404	.7114
420.9	3.13	.566	.0427	1.411	.7065
420.9	3.14	.572	.0439	1.417	.701[illegible]
420.9	3.15	.579	.0451	1.425	.6970
420.9	3.16	.584	.0463	1.432	.6923
420.9	3.17	.590	.0475	1.439	.6877
420.9	3.18	.596	.0488	1.446	.6831
420.9	3.19	.602	.0501	1.454	.6786
420.9	3.20	.607	.0513	1.461	.6742
420.9	3.21	.613	.0525	1.469	.6698
420.9	3.22	.618	.0540	1.477	.6655
420.9	3.23	.623	.0553	1.484	.6613
420.9	3.24	.628	.0566	1.492	.6572
420.9	3.25	.633	.0579	1.500	.6531
420.9	3.26	.638	.0593	1.509	.6490
420.9	3.27	.643	.0607	1.517	.6447
420.9	3.28	.648	.0621	1.525	.640[illegible]
420.9	3.29	.652	.0635	1.534	.6369
420.9	3.30	.657	.0650	1.543	.6327
420.9	3.31	.661	.0665	1.552	.6289
420.9	3.32	.665	.0680	1.561	.6249
420.9	3.33	.670	.0695	1.570	.62[illegible]
420.9	3.34	.674	.0710	1.580	.6171
420.9	3.35	.678	.0725	1.589	.6133
420.9	3.36	.682	.0741	1.599	.6095
420.9	3.37	.686	.0757	1.609	.6057
420.9	3.38	.690	.0773	1.620	.6019
420.9	3.39	.693	.0788	1.630	.5984
420.9	3.40	.697	.0805	1.640	.5947
420.9	3.41	.700	.0821	1.651	.5912
420.9	3.42	.704	.0838	1.662	.5873
420.9	3.43	.707	.0855	1.674	.5836
420.9	3.44	.710	.0872	1.6[illegible]	.5800
420.9	3.45	.713	.0889	1.697	.5765
420.9	3.46	.716	.0907	1.709	.5729
420.9	3.47	.719	.0924	1.721	.5694

RESULTS OF RUN 9 (cont.)

420.9	3.4[illegible]	.7[illegible]2	.0943	1.734	.5657
420.9	3.49	.7[illegible]5	.0961	1.746	.5626
420.9	3.50	.7[illegible]	.0977	1.759	.5592
420.9	3.51	.7[illegible]1	.0994	1.773	.5555
420.9	3.52	.734	.1013	1.787	.5520
420.9	3.53	.736	.1037	1.801	.5485
420.9	3.54	.7[illegible]9	.1057	1.815	.5451
420.9	3.55	.742	.1074	1.831	.5416
420.9	3.56	.744	.1097	1.846	.5381
420.9	3.57	.747	.1120	1.865	.5346
420.9	3.58	.749	.1142	1.886	.5310
420.9	3.59	.752	.1164	1.897	.5276
420.9	3.60	.754	.1187	1.915	.5240
420.9	3.61	.756	.1211	1.934	.5204
420.9	3.62	.758	.1234	1.953	.5168
420.9	3.63	.761	.1256	1.973	.5133
420.9	3.64	.763	.1283	1.995	.5097
420.9	3.65	.765	.1308	2.015	.5062
420.9	3.66	.767	.1334	2.037	.5026
420.9	3.67	.769	.1363	2.060	.4991
420.9	3.68	.771	.1389	2.085	.4953
420.9	3.69	.772	.1416	2.111	.4916
420.9	3.70	.774	.1445	2.139	.4879
420.9	3.71	.776	.1474	2.166	.4841
420.9	3.72	.777	.1505	2.196	.4803
420.9	3.73	.778	.1536	2.227	.4764
420.9	3.74	.780	.1568	2.260	.4725
420.9	3.75	.781	.1602	2.296	.4683
420.9	3.76	.782	.1638	2.336	.4642
420.9	3.77	.782	.1674	2.376	.4597
420.9	3.78	.783	.1713	2.425	.4554
420.9	3.79	.783	.1754	2.474	.4503
420.9	3.80	.783	.1796	2.530	.4453
420.9	3.81	.783	.1842	2.592	.4407
420.9	3.82	.782	.1891	2.662	.4356
420.9	3.83	.781	.1944	2.744	.4297
420.9	3.84	.779	.2002	2.840	.4236
420.9	3.85	.776	.2069	2.960	.4165
420.9	3.86	.771	.2148	3.121	.4083
420.9	3.87	.758	.2238	3.4[illegible]1	.3923

FLOW CHOKED IN ROTOR PASS NO. 2
TIME, 1 MINUTES AND 10 SECONDS

RESULTS OF RUN 10

RRPM	RRATE	LIAT	PC	PROP	RATIO
420.9	2.84	.277	.0121	1.242	.8831
420.9	2.85	.289	.0127	1.246	.8767
420.9	2.86	.300	.0135	1.250	.8705
420.9	2.87	.311	.0142	1.254	.8643
420.9	2.88	.322	.0151	1.258	.8583
420.9	2.89	.332	.0157	1.262	.8527
420.9	2.90	.343	.0167	1.267	.8466
420.9	2.91	.354	.0176	1.271	.8400
420.9	2.92	.365	.0184	1.275	.8335
420.9	2.93	.376	.0193	1.281	.8271
420.9	2.94	.386	.0202	1.286	.8209
420.9	2.95	.397	.0212	1.291	.8147
420.9	2.96	.407	.0221	1.296	.8088
420.9	2.97	.416	.0230	1.302	.8030
420.9	2.98	.426	.0240	1.307	.7972
420.9	2.99	.435	.0247	1.312	.7916
420.9	3.00	.444	.0259	1.317	.7861
420.9	3.01	.453	.0267	1.322	.7807
420.9	3.02	.462	.0279	1.328	.7751
420.9	3.03	.470	.0289	1.334	.7696
420.9	3.04	.478	.0299	1.339	.7641
420.9	3.05	.486	.0307	1.345	.7589
420.9	3.06	.494	.0320	1.351	.7536
420.9	3.07	.502	.0330	1.356	.7485
420.9	3.08	.509	.0341	1.362	.7435
420.9	3.09	.517	.0352	1.368	.7385
420.9	3.10	.524	.0362	1.374	.7337
420.9	3.11	.531	.0373	1.380	.7289
420.9	3.12	.538	.0385	1.386	.7241
420.9	3.13	.545	.0396	1.393	.7193
420.9	3.14	.551	.0407	1.399	.7145
420.9	3.15	.557	.0417	1.406	.7096
420.9	3.16	.564	.0431	1.413	.7048
420.9	3.17	.570	.0443	1.420	.7000
420.9	3.18	.576	.0455	1.427	.6953
420.9	3.19	.581	.0467	1.434	.6906
420.9	3.20	.587	.0479	1.442	.6860
420.9	3.21	.593	.0492	1.449	.6815
420.9	3.22	.598	.0505	1.456	.6771
420.9	3.23	.604	.0518	1.464	.6727
420.9	3.24	.609	.0531	1.472	.6684
420.9	3.25	.614	.0544	1.479	.6642
420.9	3.26	.620	.0557	1.487	.6600
420.9	3.27	.625	.0570	1.495	.6559
420.9	3.28	.630	.0584	1.503	.6518
420.9	3.29	.635	.0597	1.511	.6478
420.9	3.30	.639	.0611	1.519	.6437
420.9	3.31	.644	.0625	1.528	.6395
420.9	3.32	.648	.0640	1.537	.6355
420.9	3.33	.652	.0654	1.546	.6315
420.9	3.34	.657	.0667	1.555	.6275
420.9	3.35	.661	.0684	1.564	.6236
420.9	3.36	.665	.0699	1.574	.6197
420.9	3.37	.669	.0714	1.583	.6159
420.9	3.38	.673	.0730	1.593	.6120
420.9	3.39	.677	.0745	1.602	.6083
420.9	3.40	.681	.0761	1.613	.6045
420.9	3.41	.685	.0777	1.623	.6007
420.9	3.42	.688	.0793	1.633	.5971
420.9	3.43	.692	.0809	1.644	.5934
420.9	3.44	.695	.0826	1.655	.5897
420.9	3.45	.699	.0843	1.666	.5861
420.9	3.46	.702	.0857	1.677	.5825
420.9	3.47	.705	.0875	1.689	.5789
420.9	3.48	.708	.0891	1.701	.5754
420.9	3.49	.711	.0912	1.713	.5719

420.9	3.50	.714	.0925	1.725	.5685
420.9	3.51	.717	.0945	1.735	.5648
420.9	3.52	.720	.0966	1.750	.5615
420.9	3.53	.723	.0985	1.763	.5577
420.9	3.54	.726	.1004	1.777	.5544
420.9	3.55	.728	.1024	1.792	.5508
420.9	3.56	.731	.1044	1.806	.5472
420.9	3.57	.734	.1064	1.821	.5437
420.9	3.58	.736	.1085	1.837	.5402
420.9	3.59	.739	.1105	1.852	.5365
420.9	3.60	.741	.1127	1.869	.5333
420.9	3.61	.743	.1149	1.886	.5297
420.9	3.62	.746	.1171	1.904	.5262
420.9	3.63	.748	.1193	1.922	.5227
420.9	3.64	.750	.1217	1.940	.5172
420.9	3.65	.752	.1241	1.960	.5156
420.9	3.66	.755	.1265	1.980	.5120
420.9	3.67	.757	.1289	2.001	.5085
420.9	3.68	.759	.1314	2.022	.5050
420.9	3.69	.761	.1341	2.045	.5013
420.9	3.70	.762	.1368	2.070	.4976
420.9	3.71	.764	.1395	2.094	.4940
420.9	3.72	.766	.1423	2.120	.4903
420.9	3.73	.767	.1452	2.148	.4865
420.9	3.74	.769	.1482	2.176	.4828
420.9	3.75	.770	.1512	2.207	.4789
420.9	3.76	.772	.1545	2.240	.4749
420.9	3.77	.773	.1573	2.274	.4709
420.9	3.78	.774	.1613	2.313	.4667
420.9	3.79	.775	.1643	2.353	.4625
420.9	3.80	.775	.1685	2.397	.4581
420.9	3.81	.776	.1725	2.445	.4535
420.9	3.82	.776	.1767	2.496	.4489
420.9	3.83	.776	.1811	2.554	.4440
420.9	3.84	.776	.1857	2.619	.4389
420.9	3.85	.775	.1903	2.694	.4335
420.9	3.86	.773	.1962	2.779	.4275
420.9	3.87	.771	.2024	2.884	.4209
420.9	3.88	.768	.2095	3.014	.4135
420.9	3.89	.762	.2183	3.210	.4037
420.9	3.90	.748	.2326	3.597	.3880

FLOW CHOKED IN ROTOR PASS NO. 2
TIME, 1 MINUTES AND 11 SECONDS

RESULTS OF RUN 11

RRPM	PRATE	FIAT	PC	PZOF	VRATIO
407.4	2.62	.174	.0058	1.194	.9426
407.4	2.63	.189	.0064	1.197	.9349
407.4	2.64	.203	.0070	1.201	.9277
407.4	2.65	.217	.0078	1.204	.9204
407.4	2.66	.231	.0083	1.208	.9132
407.4	2.67	.244	.0089	1.212	.9061
407.4	2.68	.257	.0096	1.215	.8992
407.4	2.69	.270	.0103	1.219	.8925
407.4	2.70	.282	.0109	1.223	.8859
407.4	2.71	.295	.0115	1.226	.8794
407.4	2.72	.306	.0123	1.230	.8731
407.4	2.73	.318	.0130	1.234	.8667
407.4	2.74	.329	.0137	1.237	.8608
407.4	2.75	.340	.0144	1.241	.8548
407.4	2.76	.351	.0151	1.245	.8489
407.4	2.77	.362	.0157	1.249	.8432
407.4	2.78	.372	.0166	1.253	.8375
407.4	2.79	.382	.0173	1.257	.8320
407.4	2.80	.392	.0181	1.261	.8265
407.4	2.81	.401	.0188	1.265	.8212
407.4	2.82	.411	.0196	1.269	.8150
407.4	2.83	.420	.0205	1.274	.8089
407.4	2.84	.430	.0213	1.279	.8030
407.4	2.85	.438	.0221	1.284	.7972
407.4	2.86	.447	.0230	1.288	.7915
407.4	2.87	.455	.0238	1.293	.7862
407.4	2.88	.464	.0246	1.298	.7807
407.4	2.89	.472	.0255	1.303	.7753
407.4	2.90	.480	.0264	1.308	.7701
407.4	2.91	.487	.0273	1.313	.7649
407.4	2.92	.495	.0282	1.318	.7599
407.4	2.93	.502	.0291	1.323	.7547
407.4	2.94	.510	.0300	1.328	.7496
407.4	2.95	.517	.0310	1.333	.7445
407.4	2.96	.524	.0319	1.339	.7395
407.4	2.97	.531	.0329	1.344	.7345
407.4	2.98	.537	.0338	1.350	.7297
407.4	2.99	.544	.0348	1.355	.7251
407.4	3.00	.550	.0358	1.361	.7204
407.4	3.01	.557	.0368	1.366	.7158
407.4	3.02	.563	.0378	1.372	.7113
407.4	3.03	.569	.0388	1.378	.7068
407.4	3.04	.575	.0399	1.384	.7025
407.4	3.05	.581	.0410	1.390	.6977
407.4	3.06	.587	.0421	1.396	.6930
407.4	3.07	.592	.0432	1.403	.6884
407.4	3.08	.598	.0443	1.410	.6839
407.4	3.09	.603	.0454	1.416	.6794
407.4	3.10	.609	.0466	1.423	.6750
407.4	3.11	.614	.0473	1.430	.6706
407.4	3.12	.619	.0489	1.437	.6665
407.4	3.13	.624	.0501	1.444	.6622
407.4	3.14	.629	.0513	1.451	.6581
407.4	3.15	.634	.0525	1.458	.6540
407.4	3.16	.639	.0537	1.465	.6500
407.4	3.17	.643	.0550	1.472	.6460
407.4	3.18	.648	.0562	1.480	.6421
407.4	3.19	.653	.0575	1.487	.6382
407.4	3.20	.657	.0588	1.495	.6343
407.4	3.21	.662	.0601	1.503	.6304
407.4	3.22	.666	.0614	1.511	.6266
407.4	3.23	.670	.0628	1.519	.6227
407.4	3.24	.674	.0642	1.527	.6189
407.4	3.25	.679	.0656	1.536	.6151
407.4	3.26	.683	.0670	1.544	.6113
407.4	3.27	.687	.0684	1.553	.6077

RESULTS OF RUN 11 (cont.)

407.4	3.28	.691	.0698	1.561	[illegible]
407.4	3.29	.695	.0713	1.570	.6035
407.4	3.30	.699	.0728	1.579	[illegible]
407.4	3.31	.702	.0743	1.588	.5954
407.4	3.32	.706	.0758	1.598	.5906
407.4	3.33	.710	.0773	1.607	.5865
407.4	3.34	.713	.0788	1.617	.5837
407.4	3.35	.717	.0804	1.627	.5795
407.4	3.36	.720	.0820	1.637	.5781
407.4	3.37	.723	.0835	1.647	.5725
407.4	3.38	.726	.0851	1.657	.5694
407.4	3.39	.729	.0868	1.668	.5661
407.4	3.40	.732	.0884	1.679	.5628
407.4	3.41	.735	.0901	1.690	.5594
407.4	3.42	.738	.0918	1.701	.5561
407.4	3.43	.741	.0936	1.713	.5526
407.4	3.44	.744	.0953	1.724	.5496
407.4	3.45	.746	.0970	1.736	.5465
407.4	3.46	.747	.0989	1.750	.5427
407.4	3.47	.751	.1007	1.763	.5396
407.4	3.48	.753	.1026	1.776	.5362
407.4	3.49	.755	.1045	1.790	.5327
407.4	3.50	.757	.1064	1.805	.5295
407.4	3.51	.760	.1083	1.819	.5262
407.4	3.52	.762	.1104	1.834	.5229
407.4	3.53	.764	.1124	1.850	.5196
407.4	3.54	.766	.1145	1.866	.5162
407.4	3.55	.768	.1166	1.883	.5129
407.4	3.56	.769	.1188	1.900	.5095
407.4	3.57	.771	.1209	1.917	.5062
407.4	3.58	.773	.1231	1.935	.5027
407.4	3.59	.775	.1254	1.954	.4994
407.4	3.60	.776	.1278	1.974	.4961
407.4	3.61	.778	.1301	1.994	.4925
407.4	3.62	.779	.1326	2.015	.4893
407.4	3.63	.781	.1351	2.037	.4859
407.4	3.64	.782	.1376	2.061	.4826
407.4	3.65	.783	.1402	2.084	.4789
407.4	3.66	.784	.1429	2.110	.4754
407.4	3.67	.786	.1458	2.137	.4717
407.4	3.68	.787	.1487	2.166	.4680
407.4	3.69	.788	.1517	2.195	.4644
407.4	3.70	.788	.1548	2.227	.4605
407.4	3.71	.789	.1580	2.262	.4566
407.4	3.72	.790	.1613	2.299	.4527
407.4	3.73	.790	.1647	2.337	.4486
407.4	3.74	.790	.1683	2.379	.4444
407.4	3.75	.790	.1721	2.425	.4402
407.4	3.76	.790	.1761	2.476	.4356
407.4	3.77	.789	.1802	2.532	.4307
407.4	3.78	.788	.1845	2.593	.4261
407.4	3.79	.787	.1894	2.654	.4209
407.4	3.80	.785	.1946	2.745	.4153
407.4	3.81	.782	.2003	2.844	.4091
407.4	3.82	.778	.2067	2.963	.4023
407.4	3.83	.771	.2155	3.149	.3929
407.4	3.84	.760	.2264	3.434	.3808

FLOW CHOKED IN ROTOR PASS NO. 2

TIME, 1 MINUTES AND 12 SECONDS

RESULTS OF RUN 12

RRPM	RRATE	ETAT	PC	PROF	VRATIO
407.4	2.74	.274	.0109	1.225	.8811
407.4	2.75	.287	.0116	1.229	.8748
407.4	2.76	.300	.0123	1.233	.8685
407.4	2.77	.312	.0131	1.237	.8624
407.4	2.78	.324	.0138	1.240	.8564
407.4	2.79	.336	.0146	1.244	.8505
407.4	2.80	.347	.0153	1.248	.8447
407.4	2.81	.359	.0161	1.252	.8391
407.4	2.82	.370	.0169	1.256	.8335
407.4	2.83	.380	.0177	1.260	.8271
407.4	2.84	.390	.0185	1.265	.8208
407.4	2.85	.401	.0193	1.270	.8147
407.4	2.86	.410	.0202	1.274	.8087
407.4	2.87	.420	.0210	1.279	.8030
407.4	2.88	.429	.0219	1.284	.7972
407.4	2.89	.438	.0227	1.288	.7916
407.4	2.90	.447	.0236	1.293	.7860
407.4	2.91	.456	.0245	1.298	.7806
407.4	2.92	.464	.0254	1.303	.7753
407.4	2.93	.473	.0263	1.308	.7700
407.4	2.94	.481	.0272	1.313	.7646
407.4	2.95	.489	.0281	1.318	.7592
407.4	2.96	.496	.0291	1.323	.7540
407.4	2.97	.504	.0300	1.329	.7489
407.4	2.98	.511	.0310	1.334	.7438
407.4	2.99	.518	.0320	1.339	.7388
407.4	3.00	.526	.0329	1.345	.7340
407.4	3.01	.533	.0339	1.350	.7292
407.4	3.02	.539	.0349	1.356	.7245
407.4	3.03	.546	.0359	1.361	.7198
407.4	3.04	.553	.0369	1.367	.7154
407.4	3.05	.559	.0380	1.373	.7109
407.4	3.06	.565	.0390	1.379	.7060
407.4	3.07	.571	.0401	1.385	.7014
407.4	3.08	.577	.0412	1.391	.6967
407.4	3.09	.583	.0423	1.398	.6921
407.4	3.10	.589	.0434	1.404	.6875
407.4	3.11	.594	.0446	1.411	.6831
407.4	3.12	.600	.0457	1.417	.6788
407.4	3.13	.605	.0468	1.424	.6744
407.4	3.14	.610	.0480	1.431	.6701
407.4	3.15	.616	.0492	1.438	.6659
407.4	3.16	.621	.0504	1.445	.6617
407.4	3.17	.626	.0516	1.452	.6576
407.4	3.18	.631	.0528	1.459	.6535
407.4	3.19	.636	.0541	1.466	.6495
407.4	3.20	.640	.0553	1.473	.6455
407.4	3.21	.645	.0566	1.481	.6416
407.4	3.22	.650	.0579	1.488	.6376
407.4	3.23	.654	.0592	1.496	.6337
407.4	3.24	.658	.0605	1.504	.6297
407.4	3.25	.662	.0618	1.512	.6259
407.4	3.26	.666	.0631	1.520	.6221
407.4	3.27	.670	.0645	1.528	.6184
407.4	3.28	.674	.0658	1.537	.6146
407.4	3.29	.678	.0672	1.545	.6109
407.4	3.30	.682	.0687	1.554	.6072
407.4	3.31	.686	.0701	1.563	.6035
407.4	3.32	.689	.0715	1.572	.6000
407.4	3.33	.693	.0730	1.581	.5964
407.4	3.34	.697	.0745	1.590	.5929
407.4	3.35	.700	.0759	1.599	.5893
407.4	3.36	.703	.0774	1.609	.5858
407.4	3.37	.706	.0789	1.619	.5824
407.4	3.38	.709	.0804	1.628	.5790
407.4	3.39	.712	.0820	1.639	.5756

407.4	3.40	.715	.0835	1.649	.5721
407.4	3.41	.718	.0851	1.660	.5687
407.4	3.42	.721	.0868	1.670	.5654
407.4	3.43	.723	.0884	1.681	.5620
407.4	3.44	.726	.0900	1.692	.5587
407.4	3.45	.729	.0917	1.703	.5556
407.4	3.46	.731	.0934	1.715	.5521
407.4	3.47	.734	.0952	1.728	.5487
407.4	3.48	.737	.0970	1.740	.5453
407.4	3.49	.739	.0988	1.753	.5420
407.4	3.50	.742	.1007	1.767	.5386
407.4	3.51	.744	.1025	1.780	.5354
407.4	3.52	.746	.1044	1.794	.5321
407.4	3.53	.748	.1063	1.808	.5287
407.4	3.54	.751	.1083	1.823	.5254
407.4	3.55	.753	.1104	1.838	.5220
407.4	3.56	.755	.1124	1.854	.5187
407.4	3.57	.757	.1145	1.870	.5155
407.4	3.58	.759	.1166	1.886	.5121
407.4	3.59	.761	.1188	1.903	.5088
407.4	3.60	.763	.1210	1.921	.5055
407.4	3.61	.765	.1232	1.939	.5023
407.4	3.62	.767	.1255	1.957	.4989
407.4	3.63	.769	.1278	1.977	.4956
407.4	3.64	.770	.1303	1.998	.4921
407.4	3.65	.772	.1327	2.018	.4889
407.4	3.66	.773	.1352	2.041	.4854
407.4	3.67	.775	.1378	2.064	.4818
407.4	3.68	.776	.1405	2.089	.4783
407.4	3.69	.777	.1432	2.115	.4747
407.4	3.70	.778	.1460	2.142	.4711
407.4	3.71	.780	.1489	2.170	.4674
407.4	3.72	.780	.1519	2.200	.4637
407.4	3.73	.781	.1550	2.233	.4597
407.4	3.74	.782	.1582	2.267	.4560
407.4	3.75	.782	.1615	2.304	.4521
407.4	3.76	.783	.1650	2.343	.4480
407.4	3.77	.783	.1686	2.386	.4438
407.4	3.78	.783	.1723	2.431	.4396
407.4	3.79	.783	.1763	2.481	.4352
407.4	3.80	.782	.1804	2.537	.4305
407.4	3.81	.781	.1849	2.599	.4256
407.4	3.82	.780	.1897	2.670	.4205
407.4	3.83	.778	.1949	2.752	.4148
407.4	3.84	.776	.2006	2.850	.4089
407.4	3.85	.772	.2072	2.973	.4017
407.4	3.86	.766	.2153	3.147	.3930
407.4	3.87	.753	.2273	3.462	.3798

FLOW CHOKED IN ROTOR PASS NO. 2
TIME, 1 MINUTES AND 12 SECONDS

RESULTS OF RUN 13

RRPM	RRATE	ETAT	PC	PROP	VRATIO
407.4	2.77	.280	.0113	1.226	.8807
407.4	2.78	.292	.0119	1.229	.8743
407.4	2.79	.303	.0126	1.233	.8681
407.4	2.80	.314	.0133	1.237	.8620
407.4	2.81	.325	.0140	1.241	.8563
407.4	2.82	.335	.0147	1.244	.8504
407.4	2.83	.346	.0154	1.248	.8446
407.4	2.84	.357	.0162	1.253	.8380
407.4	2.85	.368	.0170	1.257	.8315
407.4	2.86	.378	.0179	1.262	.8252
407.4	2.87	.388	.0187	1.266	.8193
407.4	2.88	.398	.0195	1.271	.8132
407.4	2.89	.408	.0204	1.275	.8073
407.4	2.90	.418	.0212	1.280	.8015
407.4	2.91	.427	.0221	1.285	.7958
407.4	2.92	.436	.0229	1.290	.7902
407.4	2.93	.445	.0238	1.294	.7847
407.4	2.94	.454	.0247	1.299	.7790
407.4	2.95	.462	.0256	1.305	.7734
407.4	2.96	.470	.0266	1.310	.7679
407.4	2.97	.479	.0275	1.315	.7626
407.4	2.98	.487	.0284	1.320	.7573
407.4	2.99	.494	.0294	1.325	.7522
407.4	3.00	.502	.0303	1.331	.7471
407.4	3.01	.509	.0313	1.336	.7421
407.4	3.02	.517	.0323	1.341	.7372
407.4	3.03	.524	.0333	1.347	.7324
407.4	3.04	.531	.0343	1.352	.7277
407.4	3.05	.537	.0353	1.358	.7231
407.4	3.06	.544	.0363	1.363	.7185
407.4	3.07	.551	.0373	1.369	.7136
407.4	3.08	.557	.0384	1.375	.7087
407.4	3.09	.563	.0395	1.382	.7039
407.4	3.10	.569	.0406	1.388	.6992
407.4	3.11	.575	.0417	1.394	.6946
407.4	3.12	.580	.0428	1.400	.6902
407.4	3.13	.586	.0439	1.407	.6857
407.4	3.14	.591	.0450	1.413	.6813
407.4	3.15	.597	.0461	1.420	.6770
407.4	3.16	.602	.0473	1.427	.6727
407.4	3.17	.607	.0485	1.433	.6685
407.4	3.18	.613	.0497	1.440	.6643
407.4	3.19	.618	.0509	1.447	.6602
407.4	3.20	.623	.0521	1.454	.6562
407.4	3.21	.627	.0533	1.461	.6521
407.4	3.22	.632	.0545	1.468	.6481
407.4	3.23	.637	.0558	1.476	.6441
407.4	3.24	.641	.0570	1.484	.6400
407.4	3.25	.645	.0583	1.491	.6360
407.4	3.26	.649	.0596	1.499	.6321
407.4	3.27	.654	.0609	1.507	.6283
407.4	3.28	.658	.0623	1.515	.6244
407.4	3.29	.662	.0636	1.523	.6206
407.4	3.30	.666	.0650	1.532	.6169
407.4	3.31	.670	.0664	1.540	.6131
407.4	3.32	.673	.0677	1.548	.6095
407.4	3.33	.677	.0691	1.557	.6059
407.4	3.34	.681	.0706	1.566	.6023
407.4	3.35	.685	.0720	1.575	.5987
407.4	3.36	.688	.0735	1.584	.5951
407.4	3.37	.691	.0749	1.593	.5916
407.4	3.38	.695	.0764	1.603	.5880
407.4	3.39	.698	.0779	1.613	.5845
407.4	3.40	.701	.0794	1.622	.5811
407.4	3.41	.704	.0810	1.632	.5776
407.4	3.42	.707	.0825	1.643	.5742

407.4	3.43	.710	.0841	1.653	.5708
407.4	3.44	.713	.0857	1.664	.5674
407.4	3.45	.716	.0872	1.674	.5643
407.4	3.46	.718	.0889	1.685	.5609
407.4	3.47	.721	.0906	1.697	.5574
407.4	3.48	.724	.0923	1.709	.5540
407.4	3.49	.726	.0941	1.721	.5506
407.4	3.50	.729	.0959	1.733	.5472
407.4	3.51	.731	.0976	1.746	.5439
407.4	3.52	.734	.0994	1.759	.5406
407.4	3.53	.736	.1013	1.772	.5373
407.4	3.54	.738	.1031	1.786	.5340
407.4	3.55	.741	.1050	1.800	.5307
407.4	3.56	.743	.1070	1.814	.5274
407.4	3.57	.745	.1089	1.829	.5241
407.4	3.58	.747	.1110	1.844	.5208
407.4	3.59	.749	.1130	1.860	.5175
407.4	3.60	.751	.1151	1.876	.5141
407.4	3.61	.753	.1172	1.893	.5108
407.4	3.62	.755	.1194	1.910	.5075
407.4	3.63	.757	.1216	1.928	.5042
407.4	3.64	.759	.1239	1.946	.5009
407.4	3.65	.761	.1261	1.965	.4976
407.4	3.66	.762	.1285	1.985	.4942
407.4	3.67	.764	.1310	2.007	.4907
407.4	3.68	.765	.1334	2.029	.4872
407.4	3.69	.767	.1360	2.051	.4838
407.4	3.70	.768	.1386	2.076	.4802
407.4	3.71	.769	.1413	2.101	.4766
407.4	3.72	.770	.1441	2.127	.4731
407.4	3.73	.771	.1469	2.155	.4694
407.4	3.74	.772	.1497	2.184	.4657
407.4	3.75	.773	.1527	2.215	.4617
407.4	3.76	.774	.1560	2.249	.4581
407.4	3.77	.775	.1593	2.284	.4542
407.4	3.78	.775	.1626	2.321	.4502
407.4	3.79	.776	.1661	2.361	.4462
407.4	3.80	.776	.1698	2.405	.4420
407.4	3.81	.776	.1736	2.452	.4377
407.4	3.82	.775	.1776	2.504	.4332
407.4	3.83	.775	.1819	2.563	.4284
407.4	3.84	.774	.1863	2.627	.4236
407.4	3.85	.772	.1913	2.702	.4182
407.4	3.86	.770	.1966	2.788	.4126
407.4	3.87	.767	.2026	2.895	.4061
407.4	3.88	.763	.2097	3.035	.3985
407.4	3.89	.751	.2220	3.333	.3848

FLOW CHOKED IN ROTOR PASS NO. 2
TIME, 1 MINUTES AND 11 SECONDS

RESULTS OF RUN 14

RRPM	RRATE	ETAT	PC	PROF	VRATIC
523.4	3.24	.172	.0113	1.356	.9383
523.4	3.25	.186	.0131	1.363	.9305
523.4	3.26	.205	.0146	1.371	.9229
523.4	3.27	.221	.0160	1.378	.9154
523.4	3.28	.236	.0175	1.385	.9081
523.4	3.29	.251	.0189	1.393	.9002
523.4	3.30	.266	.0204	1.401	.8939
523.4	3.31	.280	.0219	1.408	.8872
523.4	3.32	.295	.0234	1.416	.8804
523.4	3.33	.308	.0250	1.424	.8737
523.4	3.34	.322	.0266	1.432	.8671
523.4	3.35	.335	.0282	1.440	.8607
523.4	3.36	.349	.0299	1.451	.8530
523.4	3.37	.361	.0317	1.461	.8454
523.4	3.38	.374	.0334	1.471	.8381
523.4	3.39	.386	.0352	1.482	.8308
523.4	3.40	.398	.0370	1.492	.8238
523.4	3.41	.409	.0389	1.503	.8168
523.4	3.42	.421	.0407	1.514	.8100
523.4	3.43	.432	.0427	1.526	.8032
523.4	3.44	.443	.0445	1.537	.7968
523.4	3.45	.453	.0465	1.548	.7905
523.4	3.46	.464	.0485	1.560	.7841
523.4	3.47	.474	.0505	1.572	.7779
523.4	3.48	.484	.0525	1.584	.7718
523.4	3.49	.494	.0546	1.596	.7658
523.4	3.50	.503	.0567	1.609	.7599
523.4	3.51	.513	.0587	1.621	.7542
523.4	3.52	.522	.0607	1.634	.7485
523.4	3.53	.531	.0631	1.647	.7429
523.4	3.54	.540	.0653	1.661	.7372
523.4	3.55	.548	.0676	1.676	.7311
523.4	3.56	.557	.0701	1.692	.7250
523.4	3.57	.565	.0725	1.708	.7192
523.4	3.58	.573	.0749	1.724	.7133
523.4	3.59	.582	.0775	1.741	.7075
523.4	3.60	.590	.0801	1.759	.7017
523.4	3.61	.597	.0827	1.776	.6961
523.4	3.62	.605	.0853	1.794	.6906
523.4	3.63	.613	.0881	1.814	.6847
523.4	3.64	.620	.0911	1.835	.6787
523.4	3.65	.628	.0940	1.856	.6729
523.4	3.66	.635	.0971	1.878	.6671
523.4	3.67	.643	.1002	1.902	.6611
523.4	3.68	.650	.1034	1.926	.6552
523.4	3.69	.656	.1066	1.951	.6495
523.4	3.70	.663	.1100	1.978	.6437
523.4	3.71	.670	.1135	2.006	.6378
523.4	3.72	.677	.1170	2.034	.6320
523.4	3.73	.683	.1207	2.064	.6252
523.4	3.74	.690	.1244	2.095	.6206
523.4	3.75	.696	.1283	2.129	.6147
523.4	3.76	.702	.1323	2.164	.6087
523.4	3.77	.708	.1363	2.202	.6028
523.4	3.78	.713	.1407	2.242	.5967
523.4	3.79	.719	.1450	2.284	.5907
523.4	3.80	.725	.1496	2.329	.5846
523.4	3.81	.730	.1545	2.378	.5783
523.4	3.82	.736	.1595	2.431	.5720
523.4	3.83	.741	.1647	2.490	.5653
523.4	3.84	.746	.1706	2.555	.5585
523.4	3.85	.752	.1768	2.628	.5513
523.4	3.86	.757	.1833	2.709	.5440
523.4	3.87	.762	.1907	2.806	.5358
523.4	3.88	.766	.1991	2.929	.5267
523.4	3.89	.770	.2037	3.082	.5164
523.4	3.90	.773	.2215	3.316	.5028

FLOW CHOKED IN ROTOR PASS NO. 2
TIME, 0 MINUTES AND 57 SECONDS

RESULTS OF RUN 15

RRPM	RRATE	ETAT	PC	PROE	VRATIO
594.3	3.47	.0[illegible]6	.0075	1.441	.9772
594.3	3.48	.109	.0097	1.452	.9674
594.3	3.49	.132	.0120	1.463	.9579
594.3	3.50	.154	.0143	1.475	.9489
594.3	3.51	.175	.0167	1.486	.9399
594.3	3.52	.196	.0191	1.498	.9311
594.3	3.53	.216	.0215	1.510	.9225
594.3	3.54	.236	.0239	1.523	.9141
594.3	3.55	.255	.0264	1.535	.9060
594.3	3.56	.273	.0288	1.547	.8980
594.3	3.57	.290	.0313	1.561	.8900
594.3	3.58	.307	.0338	1.574	.8822
594.3	3.59	.324	.0365	1.590	.8730
594.3	3.60	.341	.0394	1.608	.8634
594.3	3.61	.357	.0423	1.626	.8541
594.3	3.62	.372	.0452	1.644	.8451
594.3	3.63	.388	.0482	1.663	.8361
594.3	3.64	.403	.0513	1.683	.8272
594.3	3.65	.418	.0545	1.703	.8185
594.3	3.66	.432	.0577	1.724	.8101
594.3	3.67	.447	.0611	1.746	.8016
594.3	3.68	.460	.0644	1.768	.7934
594.3	3.69	.474	.0678	1.790	.7856
594.3	3.70	.487	.0713	1.813	.7776
594.3	3.71	.500	.0750	1.838	.7698
594.3	3.72	.513	.0787	1.863	.7621
594.3	3.73	.526	.0825	1.890	.7542
594.3	3.74	.538	.0867	1.921	.7456
594.3	3.75	.550	.0910	1.953	.7370
594.3	3.76	.563	.0955	1.988	.7285
594.3	3.77	.575	.1001	2.024	.7200
594.3	3.78	.587	.1049	2.062	.7115
594.3	3.79	.598	.1098	2.101	.7033
594.3	3.80	.610	.1148	2.143	.6951
594.3	3.81	.621	.1202	2.188	.6867
594.3	3.82	.633	.1258	2.237	.6783
594.3	3.83	.644	.1318	2.292	.6695
594.3	3.84	.655	.1381	2.351	.6606
594.3	3.85	.667	.1447	2.415	.6517
594.3	3.86	.678	.1513	2.485	.6426
594.3	3.87	.690	.1593	2.563	.6332
594.3	3.88	.701	.1676	2.656	.6231
594.3	3.89	.712	.1768	2.765	.6123
594.3	3.90	.723	.1873	2.902	.6003
594.3	3.91	.7[illegible]5	.2002	3.084	.5862
594.3	3.92	.750	.2250	3.521	.5594

FLOW CHOKED IN ROTOR PASS NO. 2
TIME, 0 MINUTES AND 59 SECONDS